TA-49

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# Geology and hydrology of Technical Area 49, Frijoles Mesa, Los Alamos County, New Mexico

by

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A study of the possible contamination of ground water by radioactive wastes

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## Shallow holes for moisture measurements

Twenty-three holes were drilled on the mesa surface in TA-49 (fig. 20) and two in Water Canyon (fig. 6) for the purpose of measuring moisture content and the changes in moisture content with time and depth. Areas 1 through 4 and Area 10 were of special interest because potential ground-water contaminants would be left in the ground as a result of the experimental work in these areas. These holes were drilled with a wagon drill and are 2.5 inches in diameter. They were cased with 2-inch plastic pipe.

A rough visual log was made at the time the holes were drilled by observing color changes of the air-returned cuttings and the general drilling conditions. These logs are plotted beside the graphs of moisture content. (See figs. 21-43.)

Holes WCM-1 and WCM-2, in Water Canyon, were drilled with a wagon drill using air as a cuttings carrier. These borings penetrated water in the thin alluvium at the level of water in the nearby stream, and air drilling could not be continued. The holes were drilled about 2.5 inches in diameter and cased with 2-inch plastic pipe; WCM-1 was cased to a depth of 9.9 feet with perforations the entire length; WCM-2 was cased to 9.4 feet with perforations in its lower 6 feet.

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Geology and hydrology of Technical Area 49

Frijoles Mesa, Los Alamos County, New Mexico

By

James E. Weir, Jr. and William D. Purtymun

## Abstract

Frijoles Mesa is a part of the Pajarito Plateau, a dissected ash-flow field that laps onto the Sierra de los Valles to the west and terminates in cliffs along White Rock Canyon to the east. Technical Area 49 (TA-49) occupies about 2 square miles on the northern segment of Frijoles Mesa near the center of the plateau, about 5 miles south of Los Alamos.

The rocks exposed at the surface at TA-49 are of the Bandelier Tuff of Pleistocene age. Subsurface rocks of the Santa Fe Group of Middle(?) Miocene to Pleistocene(?) age and the Tschicoma Formation of Pliocene and Pleistocene(?) age were penetrated by three deep test holes. The rocks of the Santa Fe Group, in ascending order, are: the undifferentiated unit, the Puye Conglomerate, and the basaltic rocks of Chino Mesa. Interbedded with the rocks of the Santa Fe Group are rocks of the Tschicoma Formation.

The undifferentiated unit consists of sediments laid down as alluvial-fan and flood-plain deposits. Above the undifferentiated unit is the Puye Conglomerate, which consists of two members. The lower member is a poorly consolidated channel-fill deposit called the Totavi Lentil. Overlying the Totavi Lentil is the fanglomerate member that is made up of volcanic debris. Interbedded with the fanglomerate member are the basaltic rocks of Chino Mesa and latite and quartz-latite ~~flow rocks~~ sheet of the Tschicoma Formation.

The Bandelier Tuff overlies the fanglomerate member. It consists of ash-fall and ash-flow rocks that are draped over the older rocks, filling the lows and smoothing out the topography of the older rocks. The Bandelier Tuff consists of three members. In ascending order they are: the Guaje Member, an ash-fall pumice and water-laid pumiceous tuff; the Otowi Member, a friable ash-flow tuff; and the uppermost Tshirege Member, a series of ash-flow tuffs with one thin water-laid bed near the top.

The Tshirege Member forms the finger-like mesa at TA-49. It is the most important geologic unit because test operations will place contaminants in these rocks ~~within~~ ABOUT 100 feet ~~of~~ BELOW the mesa surface. There these contaminants could be removed by water and carried into the zone of saturation.

The X-ray and chemical analyses of the tuff from the Tshirege Member indicate that they are rhyolitic in composition. Hydrologic analysis of the tuff indicated the following ranges: porosity, 19.3 to 54.7 percent; specific retention, 11.3 to 27.3 percent; specific yield, 0.6 to 42.6; permeability, 0.04 to 22 gpd (gallons per day) per square foot for consolidated samples, and 34 to 59 gpd per square foot for unconsolidated samples. Moisture content ranged from 0.2 to 8.7 percent by volume beneath the mesa, but moisture contents of tuff from a test hole in Water Canyon north of the mesa ranged from 13.3 to 36.3 percent by volume, which indicates some infiltration of water.

The soil cover on the mesa surface is characterized by a weathered zone, a water-laid pumice zone, and a soil zone. The top few feet of the Tshirege Member is composed of partly weathered tuff fragments in a matrix of clay. The weathered zone grades up into a brown clayey soil except along the northern edge of the mesa, where a layer of water-laid pumice occurs between the weathered zone and the soil zone.

Periodic moisture readings of the soil and underlying tuff, made by a neutron-scattering moisture probe, indicate little or no infiltration of water from precipitation through the soil zone. Other data collected during drilling, mapping, and hydrologic analysis of rocks of the Guaje, Otowi, and Tshirege Members of the Bandelier Tuff indicate that the soil forms a nearly perfect seal on the mesa surface and that the Bandelier Tuff has a large bulk permeability. Where the soil cover has been removed or disturbed, water in sufficient quantities would move almost vertically through the Bandelier Tuff into the Puye Conglomerate and eventually into the zone of saturation.

Stream flow in A NATURAL STREAM CHANNEL ON ~~an arroyo on~~ the surface of the mesa was measured at two moisture test holes about 700 feet apart. There was very little loss of flow between the two test holes after the channel and bank material had become saturated. No change in moisture content in the channel material or underlying tuff was detected below a depth of 3.5 feet in either of the test holes. The moisture content increased 16 percent by volume in the upper 3.5 feet while the stream was flowing. Six days after the flow ended, capillary return to the surface and evaporation had decreased this moisture content by as much as 13 percent.

The zone of saturation, or main aquifer, lies 1,000 to 1,200 feet below the mesa surface at TA-49 in rocks of the Santa Fe Group and Tschicoma Formation. No perched water was found above the zone of saturation. The gradient on the piezometric surface of the main aquifer is east-southeastward toward the Rio Grande about 50 ~~60~~ feet per mile. Data indicated that the recharge area to the main aquifer is west of TA-49 on the slopes of the Sierra de los Valles and the western part of the Pajarito Plateau. The specific capacity of three wells finished in the main aquifer range from 5.7 to 22 gpm (gallons per minute) per foot of drawdown. Pumping tests indicate an average coefficient of permeability of 180 gpd per foot per foot. The velocity of water in the main aquifer is approximately 400 feet per year. The quantity of water passing through the upper 650 feet of the aquifer beneath the test areas at TA-49 is approximately 370 acre-feet per year.

Tritium analyses indicate that the water in the main aquifer ranges in age from 13 to 20 years. The cause of differences in age could be that the water deeper in the aquifer moves more slowly and is actually older, or that some young water is being added to the aquifer by local recharge from canyon sources such as Water Canyon to the north or Frijoles Canyon to the south.

## Introduction

The Los Alamos Area Office, U.S. Atomic Energy Commission, requested support from the Geological Survey for a project at Technical Area 49 (TA-49) informally in conference September 29, 1959. The request was confirmed by a copy of a letter (JO-462) from Mr. William Ogle of the Los Alamos Scientific Laboratory to Mr. Paul Wilson, Manager of the Los Alamos Area Office.

The work of the Geological Survey was aimed at 1) providing geological information to the AEC about the rocks that underlie the area, and 2) defining the direction and rate of movement of water in the zone of aeration and the movement of ground water in the zone of saturation beneath the project area eastward to the Rio Grande.

Fieldwork began in late October 1959 and was completed in September 1960, although the most intensive part of the fieldwork was finished by May 10, 1960.

## Location and setting

Much of Los Alamos County south of the city of Los Alamos is used for test operations by the Los Alamos Scientific Laboratory. Various installations and areas in the upland surface and the canyon bottoms are designated "technical areas."

Technical Area 49 occupies about 2 square miles on the northern segment of Frijoles Mesa, 5 miles (about 10 road miles) south of Los Alamos (fig. 1). Frijoles Mesa is a part of the Pajarito

Figure 1.--Index map of part of Los Alamos and adjacent counties, New Mexico, showing the location of Technical Area 49 (TA-49).

Plateau, which is a dissected ash-flow field that laps onto the Sierra de los Valles (fig. 4) to the west and terminates in cliffs along White Rock Canyon to the east. The area is in the former Roman Vigil Grant, which is not sectionized, but projections of land divisions into the Grant area indicate that TA-49 is mainly in secs. 3 and 4, T. 18 N., R. 6 E., with minor parts of the area in secs. 33 and 34, T. 19 N., R. 6 E. and sec. 2, T. 18 N., R. 6 E.

The northern segment of Frijoles Mesa slopes gently eastward from an altitude of about 7,200 feet near the western edge of TA-49 to an altitude of about 7,000 feet at its dissected eastern end. It is bounded on the north by Water Canyon, which has been cut 300 to 400 feet below the plateau surface, and on the south by Ancho Canyon, whose floor is 100 to 200 feet below the relatively flat upland.

Frijoles Mesa and the adjacent canyons support moderate to dense vegetative growth. Pinon pine and juniper are the predominant trees, and there is a sparse growth of ponderosa pine, mainly in the canyons. Grama grass predominates as surface cover, and a few scrub oak, mostly shinnery oak, grow in isolated patches.

Water and Ancho Canyons drain eastward and are almost parallel. They empty into the Rio Grande in White Rock Canyon. Water Canyon heads on the slopes of the Sierra de los Valles. In the reach of Water Canyon, north of TA-49, a small intermittent flow of unknown origin occurs. Ancho Canyon heads near the entrance to TA-49 (fig. 6) and does not contain a perennial stream in its upper reach.

Drainage channels on the mesa trend generally east-southeastward with the gradient of the mesa surface, and many minor channels braid out on top of the mesa in flatter areas. Short tributary canyons drain into the two major canyons north and south of TA-49. The eastern part of TA-49 is drained by a rather well-developed dendritic system of channels and canyons. Most minor drainageways empty runoff into Ancho Canyon to the south.

## Previous work

Geology and ground-water conditions in the Los Alamos area have been studied by the Geological Survey and the Atomic Energy Commission under a cooperative program since 1949. An administrative report to the AEC by Griggs (1955) describes the general aspects of the geology of Los Alamos County. Surface geology on figure 4 is taken mainly from Griggs' geologic map, and stratigraphic nomenclature proposed by Griggs is used in this report.

The geology and ground-water conditions in Los Alamos County are described in a classified report by Baltz and others (1959), which appraised several areas as to the feasibility of the experimental work. The investigations in TA-49 are a result of this report.

## Personnel and acknowledgements

Work was done under the supervision of W. E. Hale, District Engineer, Ground Water Branch, U.S. Geological Survey, in Albuquerque.

The writers extend thanks to the personnel of the Los Alamos Scientific Laboratory, especially Mr. Robert W. Newman, Group Leader, J-6 Group, for close cooperation in facilitating the fieldwork. Appreciation also is expressed to the Zia Company, especially Messrs. W. C. Francis and W. P. Junge, for direct operational aid in almost all phases of the fieldwork. ~~Three to four~~ employees of the Zia Company were made available to collect cutting samples and to log drilling time. The cooperation of Buchanan and Associates in the core-drilling phase of operations is acknowledged. Support and cooperation of all people associated with work at TA-49 was in every way complete and gratifying.

## Purpose and scope of report

The study at TA-49 was made to determine whether ground water, either perched or in the zone of saturation, might be contaminated by radioactive materials that would be buried 30 to 120 feet below the surface of the mesa. This report describes the geology and hydrology ~~of the mesa~~ at TA-49, with emphasis on the rocks within about 100 feet of the surface, particularly their hydrologic properties.

The investigations having to do with the possibility that contaminants might be leached from the rock in which they were emplaced consisted of geologic mapping, subsurface geologic studies, observing and advising on drilling operations, interpreting geophysical logs of holes, conducting pumping tests, and making water-level measurements in wells. Rock samples were collected and sent to Geological Survey laboratories for petrographic description, chemical and X-ray analysis, and measurement of physical properties. Rock sampling was very intensive as ~~as~~ insurance against the possibility of missing information that could not be obtained later. ~~The~~ Samples have been catalogued and are stored in the Geological Survey office at Los Alamos and are available to interested parties for future study.

The tuff exposed in TA-49 had previously been mapped as a single unit; however, it was necessary, for the purpose of this study, to subdivide the rock into seven informal stratigraphic units. Six of these units are exposed in Water Canyon and are recognizable in the subsurface beneath Frijoles Mesa on the basis of cores, drill cuttings, or geophysical logs. The seventh unit is known only in the subsurface.

Information on the main aquifer of the Los Alamos area, which is 1,000 to 1,200 feet below the mesa surface, was obtained from three deep test wells. (The main aquifer in the Los Alamos area is the zone of saturation in the undifferentiated unit of the Santa Fe Group. The top of the zone of saturation in the main aquifer seems to rise westward into the upper units of the Santa Fe Group and the Tschicoma Formation. However, the water in the upper part of the Santa Fe Group and the Tschicoma Formation may be perched. The water in the main aquifer is under artesian pressure.) Hydrologic characteristics of the aquifer were estimated from drill cuttings, geophysical logs, and a pumping test on each of the three deep wells. The data obtained from these deep wells provide the basis for estimates of the average rate and direction of ground-water movement in the principal aquifer.

The results of laboratory investigations of physical and chemical characteristics of the rocks and chemical analyses of ground-water samples are tabulated in order to make them readily available for future study, but a detailed interpretation of these data is beyond the scope of this report.

## Techniques used and data collected

Most phases of the project were carried on simultaneously. Cores were described at the drilling sites. Drill cuttings were examined with a binocular microscope during periods when other operations were not pressing. Pumping tests were run on wells DT-5A, DT-9, and DT-10 to determine well performance and aquifer characteristics.

The locations of wells, large-diameter holes, and test holes used in this report are listed in the following table.

TA-49 ~~Area~~. Los Alamos grid locations, of test holes.

(See figs. 6 and 20.)

| | | |
|---|---|---|
| **Deep wells** | | |
| DT-5P | 111 + 32 south | 94 + 36 east |
| DT-5 | 110 + 99 | 93 + 03 |
| DT-5A | 111 + 47 | 93 + 03 |
| DT-9 | 142 + 81 | 131 + 27 |
| DT-10 | 113 + 27 | 129 + 94 |
| **Exploratory large-diameter holes** | | |
| Alpha | 111 + 16 south | 97 + 54 east |
| Beta | 83 + 63 | 91 + 89 |
| Gamma and Gamma "A" | 133 + 20 | 104 + 00 |
| **Core holes** | | |
| CH-1 | 104 + 98 south | 84 + 37 east |
| CH-2 | 105 + 70 | 97 + 85 |
| CH-3 | 114 + 94 | 82 + 06 |
| CH-4 | 120 + 33 | 95 + 68 |
| **Shallow holes for moisture measurements** | | |
| 1M-1, 2, 3, and 3A | 105 + 00 south | 84 + 00 east |
| 2M-1, 2, and 3 | 106 + 00 | 98 + 00 |
| 3M-1, 2, and 3 | 115 + 00 | 82 + 00 |
| 4M-1, 2, 3, and 4 | 120 + 00 | 96 + 00 |
| 5M-1 | 111 + 32 | 94 + 36 |
| 5M-2 | 111 + 05 | 92 + 38 |
| 6M-1 | 102 + 15 | 68 + 83 |
| 9M-1 | 116 + 67 | 88 + 44 |

Los Alamos grid locations - Continued

Shallow holes for moisture measurements - Continued

| | | |
|---|---|---|
| 9M-2 | 113 + 40 | 98 + 15 |
| 9M-3 | 117 + 02 | 104 + 57 |
| 9M-4 | 113 + 93 | 100 + 40 |
| 10M-1 | 104 + 96 | 110 + 31 |
| 10M-2 | 104 + 54 | 108 + 69 |

Large-diameter holes used for experimental purposes by the Los Alamos Scientific Laboratory. Layout of holes in areas shown on figure 2.

| | | |
|---|---|---|
| Area 1 | 105 + 00 south | 84 + 00 east |
| Area 2 | 106 + 00 | 98 + 00 |
| Area 3 | 115 + 00 | 82 + 00 |
| Area 4 | 120 + 00 | 96 + 00 |
| Area 10 | 105 + 00 | 109 + 00 |
| WCM-1 | 111 + 20 | 92 + 20 |
| WCM-2 | 145 + 00 | 102 + 20 |

Location of well in
The Los Alamos area, by section, township, range

(See fig. -.)

| | |
|---|---|
| T-1, 1A | sec. 20, T. 19 N., R. 7 E. |
| T-2, 2A | sec. 14, T. 19 N., R. 6 E. |
| T-3 | sec. 13, T. 19 N., R. 6 E. |
| T-4 | sec. 16, T. 19 N., R. 6 E. |
| H-19 | sec. 17, T. 19 N., R. 6 E. |
| L-3 | sec. 14, T. 19 N., R. 7 E. |

## Surface mapping

Geologic mapping on aerial photographs was begun early in December 1959. Stratigraphic relations were established in the area of maximum exposures on the south wall of Water Canyon.

The exposures were examined about every 400 to 500 yards to make certain of adequate control. Contacts were referred to the many vertical control points established in the field by Laboratory personnel engaged in mapping TA-49 topographically. Control points were located on the aerial photographs,and geologic contacts were drawn on the photographs (scale 1:7,000) in the field by stereoscopic methods.

The unit contacts on the photographs did not completely agree with the topographic contours. Therefore, the geologic contacts were adjusted to agree with the topographic base map. The geologic map is sufficiently accurate for all purposes anticipated. Segments of many contacts were drawn through areas where rock exposures are poor, and in these areas the contact alinement may not be exact. The areas of best exposure are along the road leading from the mesa just east of Area 10 into Water Canyon, the northern walls of canyons, and a few places in the bottoms of arroyo channels.

## Test drilling

Thirty-seven exploratory holes were drilled ranging in depth from 7 to 1,821 feet and in diameter from 2 inches to 2 feet. The five deep test wells are designated by "DT" and the number of a nearby area. These test wells include the pilot hole, DT-5P, and the wells DT-5, DT-5A, DT-9, and DT-10. Three holes, arbitrarily called Alpha, Beta, and Gamma, were drilled with a bucket auger on top of the mesa, in Water Canyon and in Ancho Canyon. A core hole was drilled in Areas 1 through 4 (fig. 2). These holes are designated by "CH" and an area number. Twenty-five shallow test holes were drilled with a wagon drill. These are designated by the number of the nearby area, a "M" for "moisture" to indicate the purpose of the holes, and the number of the hole in the area.

## Deep wells

Five wells were drilled to obtain hydrologic and geologic information about the main aquifer. The wells were located to give the widest distribution of subsurface geologic control and the best hydrologic control (fig. 6). Consideration was given to choosing the best sites for monitoring ground water for possible contamination.

Well DT-5P, just east of Area 5, was an air rotary hole drilled to determine the presence or absence of perched water (saturated zones above and separated from the main aquifer). It was completed at a depth of 692 feet as a dry hole.

Well DT-5, about 50 feet west of DT-5P, was unsuccessful. It was drilled with air rotary equipment. The air return was mostly lost into cracks and crevices in the tuff, and the hole was abandoned at a depth of 927 feet. Few samples of drill cuttings were obtained, and these were not described because samples from nearby well DT-5P had already been described. Three side-wall samples were taken from depths of 390, 490, and 500 feet to obtain undisturbed samples from that interval to supplement unsuccessful vertical coring in Areas 1 and 2.

Well DT-5A, 50 feet south of well DT-5, was drilled with rotary equipment, using mud as a drilling fluid. Circulation was very poor in the upper 520 feet of the hole. Twelve-inch casing was installed and cemented at this depth. (TABLE 1) Below 520 feet, circulation was maintained and cuttings samples were obtained to the total depth of 1,621 feet.

Well DT-9 (fig. 6) was begun as a 20-inch hole using cable-tool equipment. The hole was reduced to 16 inches at a depth of 595 feet, and drilled at that diameter to a depth of 1,300 feet, at which point it was logged geophysically and then cased with 12-inch pipe. An 11-inch hole was drilled from 1,300 to 1,901 feet and an 8-inch liner was installed (table 2).

Well DT-10 (fig. 6) was drilled with cable-tool equipment 16 inches in diameter to a depth of 1,125 feet below the land surface, at which point 12-inch casing was installed. An 11-inch hole was drilled from 1,125 feet to 1,408 feet, and an 8-inch liner was installed (table 3).

Table 1.--Casing schedule for well DT-5A

Altitude of land surface 7,143.32 feet

| Description | Depth below land surface (feet) | | Length (feet) | | Altitude of top of section (feet) |
|---|---|---|---|---|---|
| | Top | Bottom | Slotted | Blank | |
| | | 12-inch I. C. casing | | | |
| Blank | +0.3[1] | 519.7 | | 520 | 7,143.62 |
| | | 8-inch I. D. casing | | | |
| Blank | +.5[1] | 1,171.5 | | 1,172 | 7,143.82 |
| Slotted | 1,171.5 | 1,191.5 | 20 | | 5,971.82 |
| Blank | 1,191.5 | 1,279.5 | | 88 | 5,951.82 |
| Slotted | 1,279.5 | 1,289.5 | 10 | | 5,863.82 |
| Blank | 1,289.5 | 1,335.5 | | 46 | 5,853.82 |
| Slotted | 1,335.5 | 1,381.5 | 46 | | 5,807.82 |
| Blank | 1,381.5 | 1,415.5 | | 34 | 5,761.82 |
| Slotted | 1,415.5 | 1,445.5 | 30 | | 5,727.82 |
| Blank | 1,445.5 | 1,535.5 | | 90 | 5,697.82 |
| Slotted | 1,535.5 | 1,555.5 | 20 | | 5,607.82 |
| Blank | 1,555.5 | 1,591.5 | | 36 | 5,587.82 |
| Slotted | 1,591.5 | 1,615.5 | 24 | | 5,551.82 |
| Blank | 1,615.5 | 1,635.5 | | 20 | 5,527.82 |
| Slotted | 1,635.5 | 1,655.5 | 20 | | 5,507.82 |
| Blank | 1,655.5 | 1,708.5 | | 53 | 5,487.82 |
| Slotted | 1,708.5 | 1,728.5 | 20 | | 5,434.82 |

[1] See footnote at end of table

Table 1.--Casing schedule for well DT-5A - Continued

| Description | Depth below land surface (feet) | | Length (feet) | | Altitude of top of section (feet) |
|---|---|---|---|---|---|
| | Top | Bottom | Slotted | Blank | |
| | | 8-inch I. D. casing - Continued | | | |
| Blank | 1,728.5 | 1,740.5 | | 12 | 5,414.82 |
| Slotted | 1,740.5 | 1,750.5 | 10 | | 5,402.82 |
| Blank | 1,750.5 | 1,768.5 | | 18 | 5,392.82 |
| Slotted | 1,768.5 | 1,788.5 | 20 | | 5,374.82 |
| Blank | 1,788.5 | 1,819.5 | | 31 | 5,354.82 |
| Bottom of hole | | | | | 5,323.82 |
| Total 8-inch I. D. casing | | | 220 | 1,600 | |

1/ Extension of casing above land surface.

Table 2.--Casing schedule for well DT-9

Altitude of land surface 6,937.32

| Description | Depth below land surface (feet) | | Length (feet) | | Altitude of top of section (feet) |
|---|---|---|---|---|---|
| | Top | Bottom | Slotted | Blank | |
| | | 12-inch I. D. casing | | | |
| Blank | +2.0 1/ | 819.0 | | 821.0 | 6,939.32 |
| Slotted | 819.0 | 878.8 | 59.8 | | 6,118.32 |
| Blank | 878.9 | 903.2 | | 24.4 | 6,058.52 |
| Slotted | 903.2 | 934.5 | 31.3 | | 6,034.12 |
| Blank | 934.5 | 958.5 | | 24.0 | 6,002.82 |
| Slotted | 958.5 | 982.6 | 24.1 | | 5,978.82 |
| Blank | 982.6 | 1,002.4 | | 19.8 | 5,954.72 |
| Slotted | 1,002.4 | 1,036.4 | 34.0 | | 5,934.92 |
| Blank | 1,036.4 | 1,057.4 | | 21.0 | 5,900.92 |
| Slotted | 1,057.4 | 1,093.4 | 36.0 | | 5,879.92 |
| Blank | 1,093.4 | 1,142.0 | | 48.6 | 5,843.92 |
| Slotted | 1,142.0 | 1,208.4 | 66.4 | | 5,795.32 |
| Blank | 1,208.4 | 1,266.2 | | 57.8 | 5,728.92 |
| Slotted | 1,266.2 | 1,310.5 | 44.3 | | 5,671.12 |
| Blank | 1,310.5 | 1,333.0 | | 22.5 | 5,626.82 |
| Bottom of 12-inch I. D. casing | | | | | 5,604.32 |
| Total 12-inch I. D. casing | | | 295.9 | 1,039.1 | |

1/ See footnote at end of table

Table 2.--Casing schedule for well DT-9 - Continued

| Description | Depth below land surface (feet) | | Length (feet) | | Altitude of top of section (feet) |
|---|---|---|---|---|---|
| | Top | Bottom | Slotted | Blank | |
| | | 8-inch I. D. casing | | | |
| Swage | 1,313.1 | 1,317.2 | | 4.1 | 5,624.22 |
| Slotted | 1,317.2 | 1,500.0 | 182.8 | | 5,620.12 |
| Bottom of 8-inch I. D. casing | | | | | 5,437.32 |
| Total 8-inch I. D. casing | | | 182.8 | 4.1 | |

Top of 8-inch casing swage to 11 inches O. D. and run as liner to total depth of 1,500 feet, which telescopes 19.9 feet into the 12-inch casing.

1/ Extension of casing above land surface.

Table 3.--Casing schedule for well DT-10

Altitude of land surface 7,019.41

| Description | Depth below land surface (feet) | | Length (feet) | | Altitude of top of section (feet) |
|---|---|---|---|---|---|
| | Top | Bottom | Slotted | Blank | |
| | | | **12-inch I. D. casing** | | |
| Blank | +1.9 1/ | 1,078.4 | | 1,080.3 | 7,021.31 |
| Slotted | 1,078.4 | 1,128.0 | 49.6 | | 5,941.01 |
| Bottom of 12-inch I. D. casing | | | | | 5,891.41 |
| Total 12-inch I. D. casing | | | 49.6 | 1,080.3 | |
| | | | 8-inch I. D. casing | | |
| Swage | 1,096 | 1,097 | | 1 | 5,923.41 |
| Slotted | 1,097 | 1,118 | 21 | | 5,922.41 |
| Blank | 1,118 | 1,196 | | 78 | 5,901.41 |
| Slotted | 1,196 | 1,206 | 10 | | 5,823.41 |
| Blank | 1,206 | 1,228 | | 22 | 5,813.41 |
| Slotted | 1,228 | 1,258 | 30 | | 5,791.41 |
| Blank | 1,258 | 1,268 | | 10 | 5,761.41 |
| Slotted | 1,268 | 1,278 | 10 | | 5,751.41 |
| Blank | 1,278 | 1,302 | | 24 | 5,741.41 |
| Slotted | 1,302 | 1,322 | 20 | | 5,717.41 |
| Blank | 1,322 | 1,332 | | 10 | 5,697.41 |
| Slotted | 1,332 | 1,342 | 10 | | 5,687.41 |
| Blank | 1,342 | 1,368 | | 26 | 5,677.41 |
| Slotted | 1,368 | 1,408 | 40 | | 5,671.41 |
| Bottom of hole | | | | | 5,631.41 |
| Total 8-inch I. D. casing | | | 141 | 171 | |

1/ See footnote at end of table

Table 3.--Casing schedule for DT-10 - Continued

Top of 8-inch casing swaged out to 11 inches O. D. and run as liner to a total depth of 1,408 feet, which extends the 8-inch casing 32 feet into the 12-inch casing.

1/ Projecting above land surface.

## Exploratory large-diameter auger holes

The large-diameter holes Beta, in Water Canyon, and Gamma, in Ancho Canyon (fig. 6), were drilled with a bucket auger, mainly to determine whether perched water was present beneath the canyon bottoms. The large-diameter hole Alpha was drilled on the mesa surface primarily for geologic information.

Beta hole was drilled 2 feet in diameter to a depth of 100 feet. The hole was dry. Gamma hole was drilled 2 feet in diameter but was abandoned at a depth of 7 feet because of the hardness of the tuff, and a nearby 4-inch hole called Gamma A was drilled to a depth of 54 feet with the wagon drill. The hole was dry. Alpha hole was drilled 2 feet in diameter to a depth of 109 feet to obtain geologic information. The hole was dry.

## Core holes

Four core holes were drilled, one in each of Areas 1 through 4 in TA-49, mainly to obtain 2-inch diameter core samples for geologic study. Air was used as a cuttings carrier in order to obtain cores free of drilling mud and to detect zones of perched water.

The parts of the cores not used in the tests are stored in the Geological Survey office at Los Alamos. The core holes were cased with 2-inch pipe slotted in the lower 20 feet. Logs of the cores are in tables 10 through 13.

## Geophysical logs

Electrical, radioactivity, temperature, and sonic logs were run in wells DT-5, DT-5A, DT-9, DT-10, Alpha hole, and in core holes in Areas 1 through 4. (See figs. 54A-62B.)

Most of the logs were run by Schlumberger Well Surveying Corporation. Gamma-ray logs in the completed core holes were run with equipment of the Geological Survey because of the small hole diameter. The Survey also gamma-ray logged the lower 307 feet of well DT-9.

The electrical logs were used primarily to select principal water-bearing zones ~~of greatest permeability~~ for setting perforated casing. To a lesser extent these logs were used to select stratigraphic contacts.

Induction logs and laterologs were run on wells DT-5A and DT-9. Induction logs were run on well DT-10 and Alpha hole. The induction logs were not useable because of the very high resistivity of the rocks penetrated and the large diameter of the bore holes (especially Alpha hole).

Laterologs were run in wells DT-5A and DT-9 because of their better definition of units in rocks of high resistivity. The laterolog strikingly indicated the position of volcanic flows interbedded in the Santa Fe Group (figs. 55D and 56D); however, in the Bandelier Tuff at well DT-5A, the laterolog apparently did not define lithologic boundaries that were indicated on the other geophysical logs. A microlog and caliper log were run on well DT-5A.

The radioactivity logs, mainly gamma-ray, were the most useful of the logs for picking geologic contacts. The gamma-ray log yielded useable results in holes that contained no liquid or were only partly filled and holes with casing installed. The only geophysical log of the lower 307 feet of DT-9 was the gamma-ray log run with Geological Survey equipment. A study of this log showed changes in gamma radiati sufficiently well to aid in accurately choosing contacts between stratigraphic units penetrated by the well.

Temperature logs were run on wells DT-5A, DT-9, and DT-10 to obtain the general geothermal gradient and temperature of water.

Sonic logs were run only in holes or parts of holes containing liquid; consequently, these logs were run in only DT-5A, DT-9, and DT-10. The sonic logs were used to a limited extent in corroborating the upper and lower boundaries of hard layers of volcanic rocks in the aquifer. The sonic log for DT-5A also was used to estimate valu of porosity.

Data on the interval between 300 and 500 feet below the mesa surface was almost entirely determined from the geophysical logs. The logs were also used to make more precise determinations of stratigraphic contacts.

## Down-hole mapping

A large number of holes in Areas 1 through 4 and in Area 10 were dug with a bucket auger as part of the experiments conducted by the Los Alamos Scientific Laboratory at TA-49. These holes were 3 to 6 feet in diameter and 49 to 108 feet in depth. Thirty-nine of the holes were inspected in the course of this investigation and detailed geologic maps were made in 19 of the 39. This provided an opportunity to examine the structure and lithology of freshly exposed tuff and provided information on the post-depositional history of the tuff as well as a basis for interpretations of water movement.

Figures 15-18 contain the geologic maps of the holes, and table 26 includes reconnaissance notes on the holes that were inspected but not mapped. The system of designating the holes and the location of the ones that were inspected are shown on figure 2. These holes are numbered according to area and are

Figure 2.--Layout of large-diameter holes in Areas 1, 2, 3, 4, and 10 showing holes mapped and described. (Areas are shown on figure 6.)

alphabetized within each area (except Area 10). Hole 1-A was mapped early in the study as a 3-foot diameter hole and later was examined in reconnaissance as a 6-foot diameter hole.

The down-hole maps were plotted in the field on tubes covered with ruled cross-section paper at a scale of 1 inch equals 2 feet. The maps were reduced to 1 inch equals 6 feet for inclusion in this report.

Samples were collected at 5-foot intervals in the holes that were mapped for possible future study. The samples were hand-specimen size and were collected at random from the hole walls. Cuttings samples of each 5-foot interval also were obtained from these holes.

## Laboratory Investigations

Numerous analyses were run on the samples that were collected at TA-49 to obtain data on the physical characteristics of the tuff and soil. Sampling was most intensive in the interval between 50 and 120 feet beneath the surface of the mesa. Physical-properties tests and mineralogic and chemical analyses of rocks were made by Buchanan and Associates laboratories. Samples of rock were analyzed mineralogically and chemically by laboratories of the Geological Survey (tables 14, 15, and 16).

Hydrologic analyses were run by the Geological Survey on 36 rock samples to aid in evaluating water movement in the zone of aeration (table 17).

## Tests and analyses of rock samples

### Spencer J. Buchanan and Associates

About 150 samples of rock from TA-49 were tested under the direction of Buchanan and Associates, consulting engineers, Bryan, Tex. Tests performed included strength tests, thermal conductivity, specific heat, particle-size distribution, density, specific gravity, moisture content, porosity, and permeability. Moisture content was determined for about 70 samples and porosity for about 30 samples, mostly 5-inch cores from the walls of the large-diameter holes. Permeability to air was determined for 10 samples of core from the 4 core holes, and particle-size distribution was determined on 9 crushed specimens of the 10 samples analyzed for permeability.

Chemical (spectrographic) and mineralogical analyses were run on 9 of the core samples for which permeability was determined. Also, maximum stress, moisture content, density, and specific gravity determinations were made on these samples. The results of the tests and analyses were transmitted to the University of California Laboratory at Los Alamos.

### Health Division - Group H-7

About 12 samples, including cores from the core holes, 5-inch diameter side-wall cores and unconsolidated samples from the large-diameter holes, and air cuttings from the core holes were analyzed by Group H-7 for ion-exchange capacity.

## Geological Survey

~~Suites of~~ drill-cuttings samples from hole DT-5P, wells DT-5A, DT-9, and DT-10 were studied with a binocular microscope and described. The air cuttings from hole DT-5P were washed and described wet. Rotary mud-returned cuttings from well DT-5A and cable-tool cuttings from wells DT-9 and -10 had been washed when they were collected, and descriptions were made of the damp samples without further processing.

Bucket-auger samples from Alpha and Beta holes were examined with the binocular microscope and described. The bit-ground cuttings and chunk samples, if available, were examined. Some friable intervals in these holes did not yield chunk samples.

Mineralogic and chemical analyses were run on 16 samples by the Geochemistry and Petrology Branch. Two of the 16 samples analyzed chemically by the rapid-rock method (Shapiro and Brannock, 1956) also were analyzed by the classical method (Hillebrand, 1900) as a check on the relative accuracy of the rapid-rock analyses. Table 4 lists the samples and types of analyses made of each.

Table 4.--Rock samples for petrographic, chemical, spectographic, and x-ray analysis by the Geological Survey.

| Laboratory Serial No. | Hole No. | Depth | Washington, D.C. Mineralogic | Washington, D.C. Chemical Rapid rock | Washington, D.C. Chemical classical | Denver, Colorado Chemical (spectrographic) | Denver, Colorado Mineralogic (diffractometer) |
|---|---|---|---|---|---|---|---|
| 155572 (282123 1/) | 2-U | 52 | X | X | | X | X |
| 573 ( 124 1/) | 4-A | 85 | X | X | | X | X |
| 574 ( 125 1/) | 2-Y | 78 | X | X | | X | X |
| 929 | CH-1 | 45.5 | X | | | | |
| 930 | 2-H | 30 | X | X | | X | X |
| 931 | CH-2 | 65 | X | | | | |
| 932 | CH-2 | 130-132 | X | X | | X | X |
| 933 | CH-3 | 54 | X | | | | |
| 934 | CH-3 | 100 | X | | | | |
| 935 | 4-Y | 78 | X | X | | X | X |
| 936 | CH-3 | 46.5 | | X | | | |
| 937 | CH-4 | 83 | | X | | | |
| 156056 | CH-1 | 38-40 | | X | X | X | X |
| 057 | 3-Y | 105 | | X | X | X | X |
| 058 | 3-C | 58 | X | X | | X | X |
| 059 | 2-H | 58 | X | X | | X | X |

1/ Number assigned only for spectrographic analysis.

Determinations of permeability, porosity, specific yield, specific retention, and moisture content were made on most of the 36 samples analyzed by the Hydrologic Laboratory of the Ground Water Branch, Denver, Colo. Specific gravity and dry unit weight were determined for most of these samples. Mechanical analyses were run on 7 samples.

Approximate pH was determined on 9 samples. Moisture tension was determined on 10 samples and pore-size distribution was determined for 5 of those samples.

Permeability determinations were made on consolidated tuff and some of the unconsolidated samples. Unconsolidated samples were packed into ~~the~~ a permeameter cylinder.

A water sample from each deep test well was analyzed to obtain radio-chemical and chemical background concentrations in ground water. Samples from DT-5A, DT-9, and DT-10 were collected near the end of pumping tests. A bailed sample was collected from DT-10.

Water samples were collected during drilling and development from wells DT-5A, DT-9, and DT-10 to determine whether there might be chemical differences in water from different depth intervals in the aquifer.

Tritium concentration was determined in two samples from well DT-9 and one sample from well DT-5A. One sample from DT-9 was collected from the bailer when the well was 1,325 feet deep and the other sample was collected after the well was completed and near the end of the pumping test. The sample from well DT-5A was collected near the end of the pumping test.

## Geology and hydrology

A detailed study of the geology of Los Alamos County was not made during the course of this investigation. The reader is referred to a report on this area by Griggs (1955).

A detailed study of the geology and hydrology of TA-49 was made. The most important deposits in respect to the occurrence of ground water are volcanic and sedimentary rocks of Tertiary and Quaternary age. In TA-49, only rocks of Quaternary age are exposed at the surface; however, three deep test wells have been completed in rocks of Tertiary age that are exposed elsewhere in the Los Alamos area. In TA-49, rocks of Quaternary age are not less than 1,000 feet thick and probably are not more than about 1,300 feet thick. The thickness of the rocks of Tertiary age is unknown. The distribution of rocks in the Los Alamos area is shown in figure 4. The general sequence

Figure 4.--Geologic map of Los Alamos area, New Mexico.

of rock units and the general structural relations of the rocks of hydrologic importance are shown on a geologic cross section (figure 5)

Figure 5.--Geologic cross section through Frijoles Mesa from the Pajarito fault to the Rio Grande. Location is shown on figure 4. Descriptions of units are shown on figures 4 and 6.

based on test drilling and geologic mapping in TA-49 and on the geologic map.

The rock units described in this report are (ascending): the Santa Fe Group of Middle(?) Miocene to Pleistocene(?) age, the volcanic rocks of the Jemez Mountains of Pliocene and Pleistocene age, and the alluvium of Pleistocene and Recent age.

## Santa Fe Group

At TA-49, the Santa Fe Group of Middle(?) Miocene to Pleistocene(?) age is composed of: an undifferentiated unit; the Puye Conglomerate, which consists of the Totavi Lentil and the fanglomerate member; and the lower two units of the basaltic rocks of Chino Mesa.

The undifferentiated unit is a sequence of light-colored sediments laid down as coalescing alluvial-fan and flood-plain deposits in the Rio Grande depression. These sedimentary rocks seem to have been derived from the highlands to the north but may have been derived, in part, from the Sangre de Cristo Mountains to the east. The undifferentiated unit crops out along the Rio Grande and in Los Alamos and Guaje Canyons. It is present in the subsurface under most of the Pajarito Plateau.

The Puye Conglomerate consists of a thin basal river gravel overlaid by fan deposits of interlayered boulders, gravel, silt, and sand. The basal unit, called the Totavi Lentil, is arkosic and quartzitic debris, from sand to boulder size, derived principally from igneous and metamorphic rocks to the north and northeast. These gravels were deposited on the broad flood plain and channels of a large river, and they wedge out eastward and westward at the limits of the old riverbeds. The fan deposits that lap onto the Totavi Lentil are called the fanglomerate member and are composed of debris derived from volcanic rocks, mainly latite, quartz latite, and andesite, which crop out on the Sierra de los Valles to the west.

The Totavi Lentil of the Puye Conglomerate ~~un~~conformably overlies the undifferentiated unit along the Rio Grande and ~~non~~conformably overlies it in Los Alamos and Guaje Canyons. In the Los Alamos area, the Totavi Lentil crops out in Guaje and Los Alamos Canyons and southward along the Rio Grande to a point below the mouth of Ancho Canyon, where it wedges out between the underlying undifferentiated unit and the overlying basaltic rocks of Chino Mesa. It is found in the subsurface under most of the Pajarito Plateau.

The fanglomerate member of the Puye Conglomerate conformably overlies the Totavi Lentil. A zone near the top of the Totavi Lentil is composed of a mixture of pegmatitic rocks and volcanic debris. This mixed zone represents a change in source of the sediments from igneous and metamorphic terrane to volcanic terrane. The fanglomerate member interfingers with the easternmost flows of the Tschicoma Formation beneath the Pajarito Plateau and with the lower units of the basaltic rocks of Chino Mesa. The sediments of the upper part of the fanglomerate member were derived from the Tschicoma Formation, which formed the high mountain mass of the Sierra de los Valles to the west prior to the ash falls and flows of the Bandelier Tuff. The fanglomerate member consists mainly of latite, quartz latite, and andesite. In upper Guaje and Los Alamos Canyons, the fanglomerate member consists of angular boulders and grades to silt, sand, gravel, and rounded boulders eastward. The fanglomerate member is exposed in the Los Alamos area in Guaje, Rendija, Pueblo, and Los Alamos Canyons and is found in the subsurface under most of the Pajarito Plateau. It forms gray cliffs on the west side of the Rio Grande north of its junction with Los Alamos Canyon.

The basaltic rock of Chino Mesa consists of five mappable units, which originated from volcanic vents near Chino Mesa to the southeast of the Los Alamos area.[a]

The lower two units of the basaltic rock of Chino Mesa crop out along the Rio Grande south of Otowi Bridge. Unit 1 rests unconformably on the undifferentiated unit south of Ancho Canyon and to the north interfingers with the Totavi Lentil along the Rio Grande, with the upper flow of the unit conformable to the Totavi. To the west beneath the Pajarito Plateau the unit 1 interfingers with the fanglomerate member and the Tschicoma Formation.

Unit 2 of the basaltic rocks of Chino Mesa conformably overlies unit 1 and interfingers with the fanglomerate member and Tschicoma Formation west of the Rio Grande. East of the Rio Grande unit 2 interfingers with the upper unit of the undifferentiated unit and wedges out beneath flows of unit 4.

Unit 3 of the basaltic rock of Chino Mesa crops out in lower Los Alamos, Sandia, and Mortandad Canyons west of the Rio Grande and on Chino Mesa east of the river. It consists of basalt flows on a dissected surface. Unit 3 rests disconformably on unit 2 and unconformably on the Puye Conglomerate. It is equivalent in part to the old alluvium.

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a/ In Griggs' original manuscript report (1955) the basalt units were numbered 1-5 from youngest to oldest. In this report the units are numbered from oldest to youngest, in conformance with accepted stratigraphic practice.

Unit 4 of the basaltic rock of Chino Mesa consists of basalt flows capping the mesas south of Los Alamos Canyon west of the Rio Grande and on the eastern side of the Rio Grande south of Otowi Bridge. Unit 4 rests unconformably on the Puye Conglomerate and the undifferentiated unit and butts against unit 3 in lower Los Alamos Canyon.

Unit 5 of the basaltic rock of Chino Mesa consists of cinder cones and local basalt flows. It overlies with unconformity all older rock in which it is in contact. Where the Bandelier Tuff overlies the basaltic rock of Chino Mesa the contact is an unconformity.

Only the two lower units, 1 and 2, of the basaltic rock of Chino Mesa have been penetrated at TA-49. These were found in well DT-10. Basaltic rock~~s~~ of Chino Mesa ~~was~~ were not present in other wells that penetrated the same stratigraphic sequence.

The old alluvium consists of clays and gravels and is present on the mesa northeast of Guaje Canyon, west of Totavi in Los Alamos Canyon, lower Mortandad Canyon, and at the north end of Chino Mesa. It was deposited unconformably upon the Puye Conglomerate. The old alluvium is overlaid unconformably by the Bandelier Tuff. A flow, unit 3 of the basaltic rock of Chino Mesa, tongues out into the old alluvium west of Totavi. At the north end of Chino Mesa it is overlaid unconformably by the flows of unit 4. As the old alluvium ~~was~~ is not present at TA-49, it is not discussed further.

## Undifferentiated unit

### Physical characteristics

The undifferentiated unit of the Santa Fe Group is composed of friable to moderately well-cemented beds of light-pinkish-gray to light-brown siltstones and sandstones with some conglomerate and clay lenses. Bedding is generally poorly developed except for horizontal bedding found locally in the fine-grained material. The sand-size detritus is made up dominantly of quartz and feldspar and minor amounts of chalcedony, biotite, muscovite, and magnetite. Rock fragments consist of rhyolite, latite, gneiss, schist, limestone, and quartzite. The fragments of quartz, feldspar, gneiss, schist, quartzite, and limestone were derived from the east side of the Rio Grande valley and areas to the north. The fragments of volcanic origin, consisting of latite, rhyolite, tuff, and pumice, were derived from the west and occur mainly in the upper part of the unit.

Cuttings from the undifferentiated unit recovered in wells DT-5A, DT-9, and DT-10 (tables 5, 6, and 7) are a mixture of easterly and westerly derived sediments containing quartz, feldspar, quartzite, latite, rhyolite, and pumice.

At TA-49 three wells, DT-5A, DT-9, and DT-10, are bottomed in the unit. Well DT-5A penetrated 294 feet, DT-9 penetrated 144 feet, and DT-10 penetrated 7 feet. In well DT-10 the lower 7 feet of the boring was assigned to the unit by interpretation of electrical and gamma-ray-neutron logs. The total thickness of the unit in the region exceeds 2,400 feet, based on well information and exposures in lower Los Alamos Canyon (fig. 4).

The undifferentiated unit probably thins to the east and west toward the margins of Rio Grande trough in the region. The west boundary of the trough is not well known but may pass through the approximate longitude of Valle Grande. The upper surface of the undifferentiated unit ~~apparently~~ slopes about 1 degree southward in the TA-49 area.

## Puye Conglomerate

### Totavi Lentil

#### Physical characteristics

The Totavi Lentil is a gray, poorly consolidated conglomerate made up of fragments of quartzite, schist~~s~~, gneiss, and granite. It consists mainly of subrounded to well-rounded quartzite and quartz. Sorting generally is poor but well-sorted lenses of silt and sand are present sporadically. At TA-49 samples from DT-5A, DT-9, and DT-10 indicate that the Totavi Lentil consists of massive quartz, quartzite, and granitic debris. Sand-size particles consist of quartz, white feldspar, pink microcline, biotite, magnetite, tourmaline, and chalcedony, partly subrounded to well rounded.

At TA-49 the thickness of the lentil in wells DT-5A, DT-9, and DT-10 are 52, 38, and 46 feet respectively, indicating a southeastward thinning. Regionally the thickness of the unit ranges from 0 to 89 feet. It wedges out eastward in the vicinity of Canada Ancha and also wedges out in the subsurface westward. ~~(Fig. 5)~~. It is thickest (89 feet) at well T-2 in upper Pueblo Canyon and thinnest (10 feet) at hole H-19. At wells T-1 and T-3 there is 37 and 62 feet, respectively, of Totavi. Well T-4 was too shallow to penetrate the unit. The part of the lentil beneath TA-49 dips southward about 1 degree, a dip that possibly is typical of the slope of the wide channel in which the unit was deposited.

## Water-bearing characteristics

The Totavi Lentil is saturated at TA-49. It has a moderately high porosity and permeability, and readily transmits water. A pumping test of well DT-10 indicates a relatively high transmissibility for the Totavi and THE overlying ~~F~~anglomerate member and included basalt. The basalt probably has a disproportionate effect on the transmissibility of the composite section of rocks. Transmissibilities for the Totavi Lentil alone were obtained elsewhere in the Los Alamos area from wells T-1, T-2, and T-3. (See fig. 4.) Pumping tests of these wells indicate coefficients of transmissibility as follows:

| Wells | Transmissibility (gpd per foot) |
|---|---|
| T-1 | 160 |
| T-2 | 7,000 |
| T-3 | 7,800 |

The differences may be due, in part, to a smaller thickness of the unit at T-1, but they also reflect differences in lithologic character. It is inferred that velocity of water movement in the Totavi is greater than in the undifferentiated unit--an inferrence that is corroborated by interpretation of tritium analyses discussed in a later section of this report.

The heterogeneity, cross-bedding, and interlayering of silt and sand with conglomerate should result in a highly dispersive flow pattern in the Totavi.

## Fanglomerate member

### Physical characteristics

The Fanglomerate member is a gray conglomerate, composed of pebbles, cobbles, and boulders of rhyolite, latite, quartz latite, and pumice in a matrix of silt and sand. These rocks ~~are~~ WERE derived from flows associated with the volcanic rocks of the Jemez Mountains. Sorting is poor but there are tongues and lenses of fairly well-sorted pumiceous siltstone and water-laid pumice in the Fanglomerate. The degree of cementation varies from friable to well cemented. The Fanglomerate member contains large angular boulders in upper Guaje and Pueblo Canyons grading into finer and rounded material to the east.

In the western half of the Pajarito Plateau, the flow ~~rocks~~ of the Tschicoma Formation are interbedded with the Fanglomerate member by replacement and in the eastern half of the plateau some of the basaltic rocks of Chino Mesa are interbedded with the Fanglomerate member. The Fanglomerate member does not crop out at TA-49. It is interbedded with the Tschicoma Formation in the subsurface. At well DT-10 it is interbedded also with units 1 and 2 of the basaltic rocks of Chino Mesa. The Puye, Tschicoma, and the basaltic rocks apparently ~~were deposited in~~ FORMED a shallow trough trending southward beneath the western side of Pajarito Plateau (fig. 5).

At TA-49 well DT-9A penetrated 595 feet of the Fanglomerate member. Wells DT-9 and DT-10 penetrated 231 feet and 183 feet of the member, respectively. Known thickness ranges from 209 feet exposed in lower Guaje Canyon to 637 feet penetrated in well T-2 in Pueblo Canyon.

## Water-bearing characteristics

At TA-49 the lower beds of the Fanglomerate member are saturated where they are interbedded with the Tschicoma Formation and basaltic rocks of Chino Mesa. Elsewhere in the Los Alamos area, wells T-1A and T-2A in Pueblo Canyon penetrated perched water in zones of relatively low permeability in the Fanglomerate member. At TA-49 the unit probably has a moderate to low permeability; however, some beds may have high permeabilities and may readily transmit water. In general, permeability and transmissibility in the Fanglomerate member are less than in the underlying Totavi Lentil.

## Basaltic rocks of Chino Mesa

### Physical characteristics

Units 1 and 2 of the basaltic rocks of Chino Mesa were found at TA-49 in well DT-10. Unit 1 consists mainly of a reddish-brown to black, dense basalt containing olivine. In well DT-10 it is 173 feet thick and overlies the lower layer of the Fanglomerate member of the Puye Conglomerate. Unit 2 is mostly a dark-red vesicular basalt. At well DT-10 it overlies unit 1 and is 96 feet thick. It is overlaid by a latite flow of the Tschicoma Formation.

On the basis of the sonic log (fig. 57D), several intervals in the basalt units penetrated by well DT-10 are moderately to strongly jointed. These intervals are: about 1,125 to 1,130 feet, which may be an interflow zone; 1,175 to 1,210 feet; and 1,254 to 1,284 feet, which may be the most strongly jointed but may be partly a brecciated interval at the base of unit 1. These zones drilled somewhat faster than other intervals in the basalt. A 22-foot interflow or brecciated zone at the base of unit 2 is shown by the gamma-ray log also.

## Water-bearing characteristics

At TA-49 unit 1 and the lower 22 feet of unit 2 of basaltic rock of the Chino Mesa penetrated by well DT-10 are in the zone of saturation and seemingly transmit considerable quantities of water through joints and interflow zones. About 3 miles downgradient these basalts are above the zone of saturation and the water they transmit passes into the underlying units of the Santa Fe group. The upper parts of units 1 and 2 of the basaltic rocks of Chino Mesa ~~apparently~~ are vesicular and thus may have a high porosity but largely a low interstitial permeability. Cracks and joints formed as a result of shrinkage commonly transmit water very readily. The movement of water through a labyrinth of interconnected joints would be almost as free and unimpeded as flow through small channels. Dispersion might be limited locally within the basaltic rocks by dense relatively impervious parts of the basalt flows. Thus contaminants entering a strongly jointed zone might tend to stay in this zone for some distance downgradient. Elsewhere in the Los Alamos area, the basalt units appear to be above the main zone of saturation and contain perched water locally, as along White Rock Canyon where several small springs and seeps occur that apparently issue from partly saturated interflow zones.

## Volcanic rocks of the Jemez Mountains

Volcanic rocks of the Jemez Mountains along the eastern flanks of the Sierra de los Valles and on the Pajarito Plateau are composed of the Tschicoma Formation of Pliocene and Pleistocene(?) age and the younger Bandelier Tuff of Pleistocene age. The Tschicoma Formation consists of undifferentiated latite and quartz latite that are flow ~~rocks~~ and pyroclastic rocks associated with the volcanic rocks of the Jemez Mountains. They are highly fractured and jointed and some intervals contain weathered zones and interflow breccias. The latite and quartz latite rocks are widely exposed on the Sierra de los Valles (fig. 4) and are present in the subsurface beneath the Pajarito Plateau (fig. 5). These rocks were penetrated by wells DT-5A, DT-9, and DT-10 at TA-49 (figs. 5 and 6) and by test well T-4 in the city of Los Alamos and hole H-19 in upper Los Alamos Canyon. The lower part of this ~~series~~ sequence is interbedded with the fanglomerate member of the Puye Conglomerate and also with the basaltic rocks of Chino Mesa.

The Bandelier Tuff forms the Pajarito Plateau. The Bandelier Tuff laps on to the undifferentiated latite and quartz latite along the western edge of the plateau and terminates to the east in cliffs, steep slopes, and as filling in buried canyons cut in basalt along the Rio Grande. The tuff is composed of ash-fall pumice, ash flows, and water-laid volcanic ash and pumice.

## Tschicoma Formation

### Physical characteristics

The undifferentiated latite and quartz latite of the Tschicoma Formation contains large phenocrysts of plagioclase and smaller phenocrysts of quartz, biotite, hornblende, and augite in a fine-grained matrix of plagioclase, orthoclase, augite, magnetite, and varying amounts of glass. Interflow zones contain greenish-gray siltstone, clay, and rock fragments of tuff, rhyolite, and latite.

At TA-49 well DT-5A penetrated two layers of latite and quartz latite of the Tschicoma Formation. The upper layer is 126 feet thick and contains two interflow zones 4 and 5 feet thick ~~(table 5)~~ composed of clay, latite, tuff, and rhyolitic fragments. The lower layer is 26 feet thick. Well DT-9 penetrated 238 feet of undifferentiated latite and quartz latite interbedded with the Fanglomerate member.

Well DT-10 penetrated 40 feet of the undifferentiated latite and quartz latite unit of the Tschicoma Formation. Several interflow zones composed of dark-red silt and clay were penetrated. At well DT-10 the undifferentiated latite and quartz latite of the Tschicoma Formation lie on unit 2 of the basaltic rocks of Chino Mesa and are overlain by the upper part of the Fanglomerate member of the Puye Conglomerate.

The latite and quartz latite rocks were emplaced as viscous lava flows, and generally ~~usually~~ are highly jointed and fractured owing to shrinkage and flow deformation. Normally, these rocks have two or more joint or fracture systems that intersect.

## Water-bearing characteristics

At TA-49 the uppermost part of the Tschicoma Formation is in the zone of saturation in the vicinity of wells DT-5A and DT-9. The joints and fractures in these rocks provide space for water storage and avenues of great permeability and the interflow zones commonly contain some breccia that is permeable.

Elsewhere in the Los Alamos area water was found in the Tschicoma in well T-4 and hole H-19 (fig. 4). Several springs issue from interflow and contact zones between layers in the undifferentiated latite and quartz latite unit. Some of these springs are located in Guaje, Los Alamos, Pajarito, and Water Canyons, and Canon de Valle.

## Bandelier Tuff

The Bandelier Tuff consists chiefly of ash-fall and ash-flow tuff. Some thin water-laid sediments are included in the Bandelier. The unit is divided into three members: Guaje, Otowi, and Tshirege, from oldest to youngest. The Guaje Member rests unconformably on older rocks and consists of pyroclastic debris, partly water-laid. It is draped over the older topography. The Otowi Member is conformable to the underlying Guaje Member and consists of pumiceous tuff of ash-flow origin and locally near the top contains a few generally thin layers of water-laid sediments. The Tshirege Member unconformably overlies the Otowi and forms the cap of the Pajarito Plateau. In this report it is subdivided into seven units, composed mainly of ash-flow tuff at least one of which is water-laid. The units of the Tshirege are numbered 1A, 1B, and 2 through 6 from bottom to top.

## Guaje member

The Guaje member consists of ash-fall pumice and water-laid pumiceous tuff. Near the base gray lump-pumice fragments ~~up to~~ as much as 2 inches in length occur. Fragments of glass shards, and quartz and sanidine crystals are found in a cellular structure of the partly devitrified pumice. Some rounded, pebble-size fragments of light-red rhyolite are found near the top of the unit.

At TA-49 the Guaje member is ~~found~~ present in the subsurface in all three deep test wells. It is 48 feet thick in DT-9, 55 feet thick in DT-10 and 91 feet thick in DT-5A.

At TA-49 the Guaje member is above the main zone of saturation and the unit contains no perched water. Elsewhere in the Los Alamos area the Guaje contains perched water locally, as at hole H-19 in upper Los Alamos Canyon. The interstices and intercellular spaces in the pumice are small. The porosity of the Guaje averages about 40 percent but permeability generally is low. Fractures and joints are not pronounced in the Guaje member, and barely perceptible joints apparently are closed or filled by alteration material.

## Otowi Member

The Otowi Member consists of a light-gray pumiceous rhyolite tuff that is friable and weathers to a gentle slope and odd teepee-LIKE shapes. Quartz crystals, glass shards, and minor amounts of mafic minerals and varing amounts of rhyolite, latite, and pumice fragments are included in a fine-grained ash. The rock fragments are rounded. The Otowi is an ash flow and contains several water-laid beds of ash and pumice near the top. Where the unit is exposed, some of the joints are hair-line cracks that are filled WITH brown clay containing roots, and some curvilinear joints are open and enlarged by weathering.

At TA-49 the Otowi is present only in the subsurface but it crops out in Water and Ancho Canyons about 0.5 mile east of TA-49. The CONTACT BETWEEN THE Otowi and overlying Tshirege Member is erosional.

At TA-49 the top of the Otowi is from 641 to 676 feet below the surface in the deep test wells. The unit is 157 feet thick in DT-10, 126 feet in DT-9, and 198 feet in DT-5A. Well DT-5P penetrated 51 feet of the Otowi Member (table 8).

The Otowi Member may yield water to springs in upper Guaje Canyon but it does not contain perched water at TA-49. Porosity of the Otowi Member ranges from 45 to 50 percent. Interstices in the Otowi are small and permeability probably is low.

Table 3.--Sample log of well DT-5P

Drilled by rotary with air for carrier

Total depth 692 feet

Completed N vember 21, 1959

Altitude of land surface 7,144 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff: | | |
| Tshirege Member: | | |
| Unit 6: | | |
| Tuff, light-gray, pumiceous; contains dipyramidal quartz crystals, some of which are clear with white inclusions; sanidine crystals and fragments; white and yellow pumice fragments; latite and quartz latite rock fragments ---------- | 73 | 73 |
| Unit 5: | | |
| Not recognized in cuttings ---------- | 2 | 75 |
| Unit 4: | | |
| Tuff, light-purplish-gray; consists mainly of quartz and sanidine crystals and fragments; light-red rhyolite fragments -- | 44 | 119 |
| Unit 3: | | |
| Tuff, light-purplish-gray, pumiceous; includes latite and rhyolite rock fragments; quartz is very coarse sand size, clear, dipyramidal crystals; sanidine fragments are pitted. Samples decrease from 50 to 90 [illegible] ---------- | 63 | 182 |

Table 6.--Log of DT-5P - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 2: | | |
| Tuff, light-pinkish-gray; groundmass is very fine sand to silt-size ash with abundant sanidine phenocrysts and some quartz ---------- | 100 | 262 |
| Unit 1B: | | |
| Tuff, light-tan, pumiceous; quartz and sanidine crystals and fragments; light-tan pumice fragments; gray and light-red rhyolite and gray latite rock fragments; pumice fragments have dark-gray streaks along cellular structure from 379 to 412 feet; light-tan pumice; very fine-size quartz and sanidine crystals and fragments; 95 percent of sample was lost when washed from 448 to 485 ---------- | 203 | 485 |
| Unit 1A: | | |
| Tuff, light-pinkish-gray, pumiceous; light-gray and yellowish-orange pumice fragments; quartz and sanidine fragments and crystals; gray latite, light-red and gray rhyolite rock fragments; rock fragments increase from 556 to 641 feet ---------- | 156 | 641 |

Table 8.--Log of DT-5P - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Otowi Member: | | |
| Pumice, light-tan, some welded tuff fragments; light-gray and light-reddish rhyolite: 80 to 98 percent of samples lost when washed --- | 51 | 692 |

Note: Hole was drilled with a 4½-inch rock bit using air to cool the bit and clean the hole. Perched water was not present. Color determination was made from dry samples. Samples were washed and described while wet. Correlationsare based on drill cuttings from hole 5P and on gamma-ray log of hole DT-5 which is about 50 feet to the northeast of 5P.

## Tshirege Member

The Tshirege Member forms the finger-like mesas of the Pajarito Plateau. It is composed of a series of ash flows of rhyolite tuff and contains at least one thin water-laid bed near the top. The rhyolite tuff is composed of quartz and sanidine crystals and fragments, some mafic minerals, and zenoliths of gray rhyolite and latite in a fine ash matrix. The tuff varies from friable to welded. The thin water-laid bed is composed of material derived from the underlying ash flow.

The tshirege Member is entirely above the main zone of saturation at TA-49, and it contains no perched water. Adjacent to and beneath the canyons it probably contains perched water.

The Tshirege Member is the most important geologic unit in Area 49 insofar as test operations are concerned and this unit is treated in detail in a special section following the discussion of the alluvium.

## Alluvium

Alluvium in Water Canyon ~~on~~ AT the northern edge of TA-49 consists of material derived from the Tschicoma Formation that forms the Sierra de Los Valles and from the Bandelier Tuff of Frijoles Mesa into which Water Canyon is cut.

The alluvium is a poorly sorted mixture of silt, clay derived from weathered tuff, and ~~larger~~ SAND particles derived from the latites and quartz latites ~~rocks~~ of the Tschicoma Formation. The sand~~-size~~ particles consist of quartz, sanidine, dark minerals, and fragments of tuff, pumice, latite, quartz latite, and rhyolite.

The alluvium in Water Canyon ranges in thickness from 0 to about 14 feet. Test holes ~~WM-1~~ WCM-1 and 2 penetrated about 14 feet of clay, silt, and minor amounts of gravel overlying 2 to 4 feet of gravel at the base of the alluvium. At Beta hole the alluvium consists of 8 feet of silt and gravel. The stream channel in many places is cut 6 to 10 feet into the alluvium.

Clays and silts are almost impermeable when saturated but gravels or gravels with minor amounts of clay and silts will readily transmit water. In test holes WCM-1 and 2 water was (temporarily) perched in the alluvium on top of the lowest exposed unit of the Tshirege Member of the Bandelier Tuff indicating the permeability of the alluvium is greater than that of the underlying tuff.

Ancho Canyon, on the southern edge of TA-49, heads in Frijoles Mesa which is underlain by the Bandelier Tuff. Alluvium is very thin or absent in Ancho Canyon. For this reason it was not mapped on figure 6.

## Geology and water-bearing properties of the Tshirege Member of the Bandelier Tuff

The Tshirege Member ranges in thickness from about 1,000 feet in upper Frijoles Canyon to less than 100 feet along the Rio Grande.

At TA-49 the Tshirege Member has been divided into seven units (fig. 6). Unit 1A is the oldest and known only in the subsurface.

Figure 6.--Geologic map and cross section showing location of exploratory drill holes, TA-49, Los Alamos County, N. Mex.

~~Description of subsurface units are shown on figure 4.~~

The other six units, units 1B, and 2 through 6, crop out in Water Canyon and are described in a measured section (table 9).

Correlation of the units in the subsurface were made by gamma-ray-neutron and lithologic logs of the four core holes (tables 10-13) and wells DT-5P, DT-5, DT-5A, DT-9, and DT-10.

Table 9.--Typical section of units in the Tshirege Member of the Bandelier Tuff

South wall of Water Canyon - NW¼NE¼ sec. 3 (projected) T. 15 N., R. 9 E.

Measured by E. H. Baltz and W. D. Purtymun

| | Thickness (feet) |
|---|---|
| Bandelier Tuff: | |
| Tshirege Member: | |
| Unit 6: | |
| Tuff, light-grayish-pink, weathers brownish-pink, rhyolitic, moderately welded; fine-grained ash matrix; small pumice fragments; scattered quartz and sanidine crystals; approximate horizontal sheeting that may be bedding; conchoidal joints; forms cliffs, caps mesa. Lower contact is irregular ------ | 50+ |
| Unit 5: | |
| Sand, light-gray with intermixed limonitic stains, water-laid; mostly medium-grained but contains fragments up to pebble size; composed of reworked tuff containing stream-worn quartz and sanidine crystals and tuff fragments; foreset and topset bedding is well developed; forms notch near top of mesa; lower contact is irregular. Joints of underlying unit 4 are filled with sand ------ | 3.8 |

Table 9.--Type section of units in the Tshirege Member - Continued

| | Thickness (feet) |
|---|---|
| Bandelier Tuff - Continued | |
| Tshirege Member - Continued | |
| Unit 4: | |
| Tuff, light-pinkish-gray; fine-grained; 10 percent quartz crystals; small light-pink to dark-gray rhyolite fragments; small pumice fragments up to $\frac{1}{2}$ inch in length; no bedding present but lenses of disk-shaped pumice up to 6 inches in length and 2 inches thick in dense pinkish-gray matrix; weathering grades up into sand of units; forms cliff; lower contact is gradational ---------- | 41 |
| Unit 3: | |
| Tuff, light-gray, very pumiceous, friable; 20 to 30 percent granule size quartz and sanidine crystals; pumice fragments up to 1 inch in length; this description applies to lower 3 feet. Remainder of unit, except for upper 2 feet, is covered and forms slope. Small valley cut into this unit. Lower contact is covered ---------- | 40 |

Table 9.--Typical section of units in the Tshirege Member - Continued

| | Thickness (feet) |
|---|---|
| Bandelier Tuff - Continued | |
| Tshirege Member - Continued | |
| Unit 2: | |
| Tuff, light-pinkish-gray, weathering light-brownish-gray; dense, welded; 20 to 30 percent coarse-grained quartz and feldspar crystals and fragments; 10 percent pebble-size pumice fragments; gray rhyolite rock fragments; matrix crystals of fine-grained glassy material; forms cliffs consisting of two beds separated by a slight notch; lower contact with unit 1B is concealed but on north wall of canyon is irregular --------- | 100 |

Table 9.--Type section of units in the Tshirege Member - Continued

| | Thickness (feet) |
|---|---|
| Bandelier Tuff - Continued | |
| Tshirege Member - Continued | |
| Unit 1B: | |
| Tuff, gray to pinkish-gray, weathers pink to light-orange; cobble-size gray rhyolite; quartz and feldspar crystals and fragments; pumice fragments in ash matrix; weathering around quartz crystal and fragments are yellow stained; pumice weathers to brown clay; internal stratification lacking but rock fragments and pumice are in lenses; maybe two or more ash falls with irregular contacts; weathers to steep slope pitted by weathering out of pumice fragments in places. Probably is an explosive breccia ---------- | 134+ |

Table 10.--Log of core hole 1

Cored by rotary with air for carrier

Total depth 501 feet

Completed December 6, 1959

Altitude of land surface 7,170

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff | | |
| Tshirege Member | | |
| Unit 6: | | |
| Tuff, light-gray to purplish-gray pumiceous; zenoliths of gray, red and dark-gray rock fragments; medium-size quartz and sanidine crystals and fragments; dark-gray devitrified pumice up to ½ inch in length; sand-size brownish-yellow mafic minerals. Tuff is dense from 58 to 71 feet; 42.0 feet of core recovered --------- | 71 | 71 |
| Unit 5: | | |
| No recovery, interpretation from Gamma-ray log ---------- | 2 | 73 |
| Unit 4: | | |
| Tuff, light-gray to light-tan; medium- to granule-size quartz and sanidine crystals and fragments; devitrified pumice up to 1 inch in length; grayish-blue latite rock fragments; 5.4 feet of core recovered - | 41 | 114 |

Table 11.--Log of core hole 2 - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 4: | | |
| Tuff, light-gray with slight lavender cast; very coarse to granule quartz and feldspar crystal fragments; devitrified pumice fragments up to 1 inch in length; zenoliths of light grayish-green dense rock; 40 feet of core recovered ---------- | 56 | 136 |
| Unit 3: | | |
| No recovery ---------- | 55 | 191 |
| Unit 2: | | |
| Tuff, light-purplish-gray, dense, welded; quartz and sanidine crystals up to granule size; devitrified pumices up to ½ inch in length; zenoliths of dark-gray rock fragments up to ½ inch in length; 67.9 feet of core recovered ---------- | 101 | 292 |

Table 11.--Log of core hole 2 - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 1B: | | |
| Tuff, light-pinkish-gray, pumiceous; quartz and sanidine crystals up to granule size; devitrified pumice 3/4 inch in length and 3/8 inch wide; 3.8 feet of core recovered --------- | 195 | 487 |
| Unit 1A: | | |
| No recovery ---------- | 14 | 501 |

Correlation based on recovered core and gamma-ray logs.

Table 11.--Log of core hole 2 - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 4: | | |
| Tuff, light-gray with slight lavender cast; very coarse to granule quartz and feldspar crystal fragments; devitrified pumice fragments up to 1 inch in length; zenoliths of light grayish-green dense rock; 40 feet of core recovered ---------- | 56 | 136 |
| Unit 3: | | |
| No recovery ---------- | 55 | 191 |
| Unit 2: | | |
| Tuff, light-purplish-gray, dense, welded; quartz and sanidine crystals up to granule size; devitrified pumices up to ½ inch in length; zenoliths of dark-gray rock fragments up to ½ inch in length; 67.9 feet of core recovered ---------- | 101 | 292 |

Table 11.--Log of core hole 2 - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 1B: | | |
| Tuff, light-pinkish-gray, pumiceous; quartz and sanidine crystals up to granule size; devitrified pumice 3/4 inch in length and 3/8 inch wide; 3.8 feet of core recovered --------- | 195 | 487 |
| Unit 1A: | | |
| No recovery ---------- | 14 | 501 |

Correlation based on recovered core and gamma-ray logs.

A sample from unit 5 of the Tshirege Member of the Bandelier Tuff was analyzed petrographically by C. S. Ross of the Geological Survey (written communication, July 7, 1960). Ross recalculated the proportions of phenocrysts to represent proportion by weight. The following is the result of the analysis.

## Unit 5

### Physical characteristics

Unit 5 is friable water-laid medium to coarse sand composed of worn quartz and sanidine crystals and fragments of reworked tuff as large as boulder size.

Topset and foreset bedding is well developed. Some limonite stains and a few stringers of brown clay are oriented with the cross-bedding in the unit (fig. 11). Unit 5 weathers to form a

Figure 11.--Water-laid sand of unit $\mathfrak{Q}bt_5$ of the Tshirege Member of the Bandelier Tuff underlain by weathered iron-stained unit $\mathfrak{Q}bt_4$, southeast wall of west hole in Area 10, TA-49, Los Alamos County, N. Mex.

notch on cliffs between the underlying and overlying units.

Joints in outcrops of unit 4 contain weathered brownish clay. Joints in the unit in large diameter holes varied from closed to open. In the upper part of the unit, joints are filled with sand from unit 5, indicating that these joints and fractures were open during the deposition of unit 5. In some of the large-diameter holes (figs. 15, 17, and 18) the tuff of unit 4 is friable and weathered below the contact with unit 5.

If water were transmitted by percolation to unit 5, it would further percolate downward through the permeable sand-filled joints to the open joints.

## Water-bearing characteristics

Unit 4 was dry at TA-49. Natural moisture content was very low, ranging from 0.4 to 2.2 percent by volume. The porosity of four samples of unit 4 ranged from 32.7 to 54.3 percent by volume, and specific retention ranged 11.6 to 21.8 percent by volume. The porosity decreased with depth due to the denser welding within the flow. The specific retention increased with a decrease in porosity due to a decrease in pore size which would tend to hold water under tension. Vertical permeabilities ranged from 13 gpd per square foot for the more porous tuff to 0.3 gpd per square foot for the less porous tuff found lower in the section. Horizontal permeabilities ranged from 0.4 to 13 gpd per square foot and decreased with depth. The horizontal permeability in one sample from hole 3-A was 8, and vertical permeability was 5 gpd per square foot (table 17). This difference of permeability may be related to possible near horizontal orientation of interstices in the ash-flow ~~rock~~.

Sample from Core hole 2, depth 130 to 132 feet

Pore space about 30 percent

Phenocrysts about 34 percent by weight

Sanidine 30 percent

Quartz 12 percent

Magnetite 1± percent

Pyroxene 0.5 percent

The groundmass is a typical devitrified welded tuff, the devitrification product being cristobalite and feldspar. Gas-phase reaction has resulted in secondary growths on the sanidine and development of tridymite and feldspar in vesicules. Plate-like crystals of tridymite are unusually large as are the gas-phase and devitrification minerals.

Sample from ~~of~~ Core hole 3, depth 100 feet

Pore space about 30 percent

Phenocrysts about 38 percent by weight

Sanidine 24 percent

Quartz 12 percent

Pyroxene (largely clino) 1 percent

Magnetite 1 percent

No zircon observed

Groundmass contains abundant tridymite and gas-phase, secondary growth on sanidine. Devitrification products are unusually coarse-grained. Sample contains inclusions of andesite.

Sample from Hole 4-A, depth 85 feet

Pore space about 30 percent

Phenocrysts about 32 percent by weight

Sanidine 22 percent

Quartz 11 percent

Pyroxene 0.7 percent (ortho, dominant; clino, present)

Magnetite 1.0 percent

Groundmass is devitrified shards containing unusual feldspar-cristobalite aggregates. Vesicular cavities contain gas-phase tridymite and feldspar. The sanidine phenocrysts contain secondary addition of feldspar (gas-phase) material. The sample contains an unusually large proportion of pumice grains.

Sample from Hole 4-Y, depth 78 feet

Pore space about 30 percent

Phenocrysts about 27 percent by weight

Sanidine 15 percent

Quartz 10 percent

Magnetite 1± percent

Pyroxene 0.5± percent

Groundmass is typical devitrified, welded tuff showing usual submicroscopic intergrowth of cristobalite and feldspar. Gas-phase reaction resulted in additions to sanidine phenocrysts, and tridymite and feldspar in cavities. Dark porous areas up to 15mm in diameter represent pumice fragments. A few small areas of andesitic rock are present.

## Unit 4

### Physical characteristics

Unit 4 is a light-gray to light-pinkish-gray rhyolite tuff that contains phenocrysts and fragments of medium sand- to granule-size quartz and sanidine crystals in a moderately welded ash matrix. Also present are fragments of pink to light-gray rhyolite and dark-gray pumice. Some of the pumice fragments are devitrified. Unit 4 is not bedded at the measured section in Water Canyon; however, lenses of disk-shaped dark-gray pumice fragments as much as 6 inches long and 2 inches thick are present in a dense pinkish-gray tuff.

In the outcrop the moderately welded tuff contains clay filled joints and fractures. In the large-diameter holes, joints are open as much as ½ to 2 inches. Air blowing from open joints in response to declining barometric pressure indicates that the joints are interconnected in hole 4-U. Parts of this unit form cliffs in the canyon walls.

Four samples from unit 4 of the Tshirege Member of the Bandelier Tuff were analyzed petrographically by C. S. Ross of the Geological Survey (written communication, July 7, 1960). Ross recalculated the proportions of phenocrysts to represent proportion by weight. The following are results of these analyses.

## Water-bearing characteristics

Unit 3 is dry at TA-49. Natural moisture content ranged from 0.2 to 2.9 percent by volume (table 17). One chunk sample had a porosity of 48 percent by volume and a permeability of 22 gpd per square foot.

The few joints that can be seen on the outcrop are filled with brown clay, produced by weathering of the tuff. Joints at depth presumably are open because drilling fluid was lost in this unit. The maintenance of circulation of either air or mud during drilling was difficult. Only a small amount of cuttings was recovered from unit 3; the rest were probably carried into open joints.

Table 19.--Sample log of Alpha hole - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 4: | | |
| Tuff, light-gray; medium to coarse quartz and sanidine crystals and fragments; gray devitrified pumice; light-gray rhyolite ~~rock~~ fragments, subrounded; friable zone 78 to 85 feet; moderately welded 85 to 128 feet ---------- | 50 | 128 |
| Unit 3: | | |
| Tuff, light-gray, friable; medium-size quartz and sanidine crystals and fragments; gray and white devitrified pumice fragments up to ½ inch in length; gray rhyolite ~~rock~~ fragments, pebble size; coating of yellow weathering stain around quartz fragments; large amount of very light-gray pumice; samples from 166 to 189 are pinkish-gray and moderately welded ---------- | 61 | 189 |

Table 19.--Sample log of Alpha hole

Drilled by rotary bucket

Total depth 189 feet; diameter 2 feet

Completed February 6, 1960

Altitude of land surface 7,125 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff | | |
| Tshirege Member | | |
| Unit 6: | | |
| Tuff, light-gray, moderately welded; contains fine- to medium-size quartz and sanidine crystals and fragments; yellowish-tan to gray pumice and gray devitrified pumice fragments; light-red latite and gray rhyolite ~~rock~~ fragments in a fine-grained light-gray ash matrix. Hard layer was encountered at 54 feet | 76 | 76 |
| Unit 5: | | |
| Sand, light-gray, friable; fine- to coarse-size quartz and sanidine fragments subrounded; quartz has coating of yellow weathering stain; fragments of tuff and pumice | 2 | 78 |

## Unit 3

### Physical characteristics

Unit 3 is a friable and pumiceous light-gray rhyolite tuff that contains medium to very coarse sand-size phenocrysts of sanidine and quartz crystals and fragments, gray and white devitrified pumice fragments up to ½-inch in length, an abundance of light-gray pumice, and gray rhyolite and latite rock fragments in a fine-grained glassy ash matrix. Some quartz fragments are coated with a yellow weathering stain and others are clear. Sanidine fragments appear to be pitted. Surface exposures of unit 3 are very poor. The unit weathers to a slope on which soil has developed. The best description of unit 3 is based on cuttings from Alpha hole (table 19). Core recovery from the unit was poor.

At TA-49 the thickness of unit 3 ranges from 40 feet at the measured section in Water Canyon to 76 feet in core hole 1. Thicknesses of the unit penetrated in other borings are as follows: DT-9, 58 feet; and DT-10, 57 feet.

Although the permeability of unit 2 is low, the open joints and fractures in it would transmit water rapidly. Columnar jointing is present locally in the outcrop. A core taken at 261 feet in core hole 1 contained a nearly vertical joint plated with clay which indicates that water had percolated through joints and fractures in the rocks to fairly great depth. Weathering of the tuff adjacent to the joint probably occurred during the deposition of unit 5, which is a fluvial sand. The low moisture content indicates that water presently is not moving through unit 2.

## Water-bearing characteristics

Unit 2 is dry at TA-49. The natural moisture content of the rock in unit 2 is about 0.2 percent by volume, based on five samples from core holes 2, 3, and 4. The porosity of the five samples from unit 2 that were tested range from 19 to 37 percent by volume and specific retention ranged from 11 to 21 percent by volume (table 17). Permeability was 0.04 to 2 gpd per square foot.

The fill used in building the leveled area where Gamma and Gamma "A" holes are located is composed of broken tuff and soil. Gamma hole penetrated about 6 feet of fill, and Gamma "A" hole penetrated about 10 feet of fill overlying unit 2. Spring snowmelt percolated into the fill, and perched above welded tuff of unit 2. This perched water ran into Gamma and Gamma "A" holes. Gamma hole is 2 feet in diameter and 7.15 feet deep. It was dry when drilled on February 26, 1960, but on May 2, 1960 the water level was 5.85 feet. Gamma "A" hole is 4 inches in diameter and 54 feet deep. It was dry when drilled on February 26, 1960, and on March 30 the water level was 43.6 feet. The hole was dry on May 2, 1960. Gamma "A" hole is cased with 10 feet of 4-inch steel casing which extends 1.90 feet above land surface. The water gained entry into the well through 1.90 feet of uncased fill above unit 2.

## Unit 2

### Physical characteristics

Unit 2 is a light-pinkish-gray to purplish-gray rhyolite tuff. It is hard, welded, and contains coarse sand- to granule-size phenocrysts of quartz and sanidine crystals and fragments, light-gray to gray rhyolite and latite rock fragments, and gray pumice fragments up to 2-inch long in a fine-grained, glassy ash. The outcrop of unit 2 stands as cliffs, which weather to a light brownish gray, and consists of two beds of about equal thickness separated by a slight notch. Unit 2 exhibits columnar jointing in the form of hexagonal pinnacles standing 10 to 20 feet in height and from 5 to 8 feet in diameter, west of Beta hole in Water Canyon.

Unit 2 ranges in thickness from 82 feet in core hole 3 to 111 feet in core hole 4 at TA-49. Thicknesses of unit 2 penetrated in other core holes and wells are as follows: core hole 1, 94 feet; core hole 2, 101 feet; well DT-5, 100 feet; well DT-9, 98 feet; and well DT-10, 90 feet. In the measured section in Water Canyon unit 2 is 100 feet thick. Structure contours on the top of unit 2 indicate a gentle 1- to 2-degree dip southeasterly with an undulating surface (Fig. 7).

Figure 7.--Structure contours on unit $qbt_2$ Tshirege Member of the Bandelier Tuff, TA-49, Los Alamos County, N. Mex.

## Water-bearing characteristics

Free water was not found in unit 1B at TA-49, but cuttings from unit 1B from Beta hole contained considerably more moisture than samples from lithologically similar units higher in the section.

Interstices in the matrix of unit 1B probably are small and its permeability is low, although locally the porosity may be relatively high. Clay nodules in cuttings from Beta hole in Water Canyon contained 45 to 60 percent moisture by volume, but other samples, composed mostly of ash, contained 13 to 36 percent moisture (table 17). Moisture content of a core from unit 1B, core hole 2, is less than 1 percent.

The section of unit 1B penetrated by the Beta hole is weathered and highly altered due to water infiltrating from the canyon floor.

Unit 1B weathers to a light pink or orange and is pitted by the weathering out of large pumice fragments. On the north wall of Water Canyon unit 1B is characterized by a steep slope that is broken by a bench about 20 feet below the contact with unit 2. This bench extends from TA-49 eastward to Highway 4.

At TA-49 unit 1B ranges in thickness from 195 feet in core hole 2 to 243 feet in wells DT-9 and DT-10. Core holes 1, 3, and 4 are bottomed in the unit and penetrated 217 feet, 25 feet, and 15 feet, respectively. Wells DT-5, DT-5P, and DT-5A penetrated 203 feet of unit 1B.

Table 18.--Sample log of Beta hole - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Drilling stopped at 180 feet in a rhyolite and latite tuff breccia, edges of fragments subrounded; ground mass a light-brownish-tan, pumiceous, friable tuff --------- | 172 | 180 |

Table 18.--Sample log of Beta hole

Drilled by rotary bucket

Total depth 180 feet

Completed February 25, 1960

Altitude of land surface 6,801 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Recent alluvium ---------- | 3 | 3 |
| Bandelier Tuff | | |
| Tshirege Member | | |
| Unit 1B; | | |
| Tuff, light-pinkish-tan to light-gray, pumiceous, friable; quartz and sanidine fragments and crystals up to granule size; mafic mineral stains and some mafic minerals; devitrified pumice fragments up to ½ inch in length; light-yellowish pumice; gray glassy pumice; dark-gray pumice fragments; some rhyolite ~~rock~~ fragments; samples from 61 to 81 feet are light red. Samples from 105 to 180 feet contain brown nodules of clay up to 6 inches in length; these appear to be large pumice fragments that altered to clay; the clay appears platy in places and near edge grades into highly altered cellular pumice; some gray rhyolite and light-red latite ~~rock~~ fragments are found in this interval ---------- | ~~172~~ | ~~180~~ |

## Unit 1B

### Physical characteristics

Unit 1B is a light-gray to very light-orange rhyolite tuff that contains quartz and feldspar crystals and fragments, large to small pumice fragments, and gray subrounded rhyolite and latite ~~rock-~~ fragments as much as cobble size. Unit 1B is an explosion breccia. Cuttings, samples, and outcrops show yellow weathering stains around quartz crystals and fragments. The pumice weathers to a brown clay. Stratification is lacking, but rock fragments and pumice commonly occur in lenses. The contact with the overlying unit 2 is irregular.

Beta hole, in Water Canyon, penetrated 172 feet of unit 1B (table 18). Drill cuttings from the bottom 75 feet of the boring contain nodules of brown clay as much as 6 inches long, which probably are the weathered product of large pumice fragments. The clay nodules are platy and fibrous near the center and grade to highly altered cellular pumice at the edges.

## Water-bearing characteristics

Unit 1A is dry at TA-49. Little is known of its potential water-bearing properties; however, mud circulation was maintained through this unit in well DT-5A, and its fracture permeability must be relatively low.

Joints and fractures are probably present in unit 1A, but because it is a friable unit they probably are closed or only slightly open. Water percolating through open joints and fractures in the unit probably would cause the alteration of the tuff to clay and would eventually seal them.

## Unit 1A

### Physical characteristics

Unit 1A consists of light-gray to light-pinkish-gray, pumiceous, friable rhyolite tuff that contains quartz and sanidine crystals and fragments, and rhyolite and latite fragments, and minor amounts of dark-green mafic minerals. Some of the sanidine fragments are stained dark-brown.

Unit 1A overlies the Otowi Member and does not crop out at TA-49. Unit 1A is 214 feet thick in well DT-9, 196 feet thick in DT-10, and 156 feet thick in DT-5P. It is an ash flow, the eastern end of which is deposited in a depression in older rocks beneath TA-49. It thickens southeastward from TA-49 then thins eastward and wedges out between unit 1B of the Tshirege Member and Otowi Member of the Bandelier Tuff (fig. 5).

The following ranges in permeability were obtained by analysis of samples (table 17) from units 1B, 2, 3, 4, 5, and 6 of the Tshirege Member: 0.04-22 gpd per square foot for consolidated samples, 34-59 gpd per square foot for unconsolidated samples that were repacked in permeameter cylinders; specific yield 0.6-42.6 percent; porosity 19.3-54.7 percent; specific retention 11.3-27.3 percent; dry unit weight 1.17-2.05 grams per cubic centimeter; specific gravity (grain density) 2.32-2.58 grams per cubic centimeter; moisture content 0.2-36.3 percent by volume, 0.1-43.2 percent of dry weight; and approximate pH 7.5-7.9. Mechanical analyses made on seven unconsolidated samples from units 1B, 3, and 5 (table 24) indicated rather large ranges in particle sizes from clay through medium gravel. Samples from units 1B and 3 probably have little value as these are mostly bit-cut samples. Samples from unit 5 are unconsolidated samples obtained while mapping large-diameter holes. Pore-size distribution of 10 samples from units 4, 5, and 6 are shown on table 25.

The porosity and permeability of the Tshirege Member depends upon the degree of welding and amount of weathering of individual ash flows. Joints and fractures are numerous, especially in the welded units. The joints and fractures that are open probably would transmit water rapidly.

The X-ray analyses of samples from units 4, 5, and 6 of the Tshirege Member indicate~~s~~ that these rocks are 25 to ~~50~~ 75 percent feldspar that is largely sanidine, 0 to 25 percent quartz, 0 to 25 percent tridymite, and 10 to 75 percent cristobalite. Some of the samples contain as much as 10 percent clay, probably montmorillonite (table 14). Chemical analyses of samples from these units show the following ranges in percentage of constituents analyzed: silica ($SiO_2$) 72.0-78.2, alumina ($Al_2O_3$) 11.2-13.8, ferric oxide ($Fe_2O_3$) 1.1-2.1, ferrous oxide (FeO) 0.21-0.75, magnesium oxide (MgO) 0.02-0.33, calcium oxide (CaO) 0.26-1.17, sodium oxide ($Na_2O$) 3.5-4.5, potassium oxide ($K_2O$) 4.2-4.7, water ($H_2O$) ~~0.28~~ 0.15-2.8, titanium oxide ($TiO_2$) 0.10-0.32, phosphorus oxide ($P_2O_5$) 0.01-0.07, manganese oxide (MnO) 0.00-0.08, and carbon dioxide ($CO_2$) less than 0.05 (table 15). Spectrographic analyses (table 16) of samples from these units showed rather uniform content of major and minor elemental constituents analyzed.

Table 14.--Mineral constituents of the Tshirege member of the Bandelier tuff at TA-49, Los Alamos County, N. Mex.[1/]

Results are coded according to the following system: 1 = 75-100 percent, 2 = 50-75 percent, 3 = 25-50 percent, 4 = 10-25 percent, 5 = 0-10 percent, 2-3 = 35-65 percent, 4-5 = 5-15 percent.

| Sample location | | Stratigraphic | Mineral constituents[2/] | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| Hole | Depth (feet) | Unit | Feldspar | Quartz | Tridymite | Cristobalite | Clay | |
| CH-1 | 38-40 | $Qbt_6$ | 2 | 5 | 4 | 4 | - | |
| 2-H | 30 | $Qbt_6$ | 2-3 | 5 | 4 | 4 | - | |
| 2-H | 58 | $Qbt_6$ | 2 | 4 | 5 | 4 | 5 | |
| 2-U | 52 | $Qbt_6$ | 3 | 5 | 5 | 3 | 5 | Feldspar (sanidine?). Clay (montmorillonitic). |
| 2-Y | 78 | $Qbt_5$ | 3 | 4-5 | 5 | 3 | 5 | Feldspar (sanidine?). |
| CH-2 | 130-132 | $Qbt_4$ | 2 | 4 | 5 | 4 | 5 | |
| 3-C | 58 | $Qbt_6$ | 2 | 5 | 4 | 4 | - | |
| 3-Y | 105 | $Qbt_4$ | 2 | 5 | 4 | 4 | 5 | |
| 4-A | 85 | $Qbt_4$ | 3 | 5 | 5 | 2 | 5 | Feldspar (sanidine?). Clay (montmorillonitic). |
| 4-Y | 78 | $Qbt_4$ | 2 | 4 | 5 | 4 | 5 | |

1/ Analyst: Theodore Botinelly of the Geochemistry and Petrology Branch of the U.S. Geological Survey

2/ Quantities are estimated on the basis of peak heights of diffractometer patterns. A precise identification of the clays was not made; on the basis of bulk patterns and patterns of oriented samples the clays probably are montmorillonite. The feldspars probably are sanidine based on some minor shifts of peak positions in the sample.

Table 13.--Log of core hole - - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 1B: | | |
| Tuff, light-purplish-pink to light-purplish-gray; granule size quartz and sanidine size quartz and sanidine crystals and fragments; light-gray rhyolite rock fragments; some mafic staining; pebble-size devitrified pumice fragments; 4.7 feet of core recovered ---------- | 15 | 303 |

Note: Correlation based on recovered core and gamma-ray logs.

Table 13.--Log of core hole 4 - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 4: | | |
| Tuff, light-purplish-gray; very fine-grained groundmass with about 50 percent quartz and sanidine phenocrysts; some purplish-brown devitrified pumice; medium-gray latite and quartz latite rock fragments; tuff appears dense and size of rock fragments increase from 104 to 109 feet; 28.6 feet of core recovered ---------- | 61 | 125 |
| Unit 3: | | |
| No recovery ---------- | 52 | 177 |
| Unit 2: | | |
| Tuff, light-purplish-gray, dense, welded; quartz and sanidine crystals and fragments up to granule size; medium-gray to dark-gray rhyolite rock fragments; a few light-gray devitrified pumice fragments as much as ¼ inch in length; 79.0 feet of core recovered -- | 111 | 288 |

Table 13.--Log of core hole 4

Cored by rotary with air for carrier

Total depth 303 feet

Completed February 5, 1960

Altitude of land surface 7,116 feet

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff | | |
| Tshirege Member | | |
| Unit 6: | | |
| Tuff, light-gray to light-pinkish-gray; very fine-grained groundmass with very coarse-grained phenocrysts of quartz and sanidine; light-purplish-gray devitrified pumice up to 3/4 inch in length; granule-size medium-gray latite rock fragments; 44.1 feet of core recovered ---------- | 62 | 62 |
| Unit 5: | | |
| No recovery, interpretation from gamma-ray log ---------- | 2 | 64 |

Table 12.--Log of core hole 3 - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 1B | | |
| Tuff, light-purplish-pink to gray, dense, welded; granule-size quartz and sanidine crystals and fragments; purplish-pink devitrified pumice fragments; gray rhyolite rock fragments; gray rhyolite fragments increase from 295 to 300 feet; 23.2 feet of core recovered ---------- | 25 | 300 |

Note: Correlation based on recovered core and gamma-ray logs.

Table 12.--Log of core hole 3 - Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff - Continued | | |
| Tshirege Member - Continued | | |
| Unit 4: | | |
| Tuff, light-purplish-pink; fine-grained groundmass with 50 percent sanidine and abundant very coarse-grained medium-gray rock fragments; elongated devitrified pumice fragments up to 1 inch in length; decrease in rock fragments and pumice from 105 to 111 feet; 15.5 feet of core recovered ---- | 44 | 121 |
| Unit 3: | | |
| Tuff, purplish-pink to gray, very pumiceous; no core recovery; sample taken with basket ---------- | 72 | 193 |
| Unit 2: | | |
| Tuff, light-gray to purplish-gray, welded, dense; quartz and sanidine crystals and fragments up to granule size; light-gray phenocrysts of rhyolite rock fragments; devitrified pumice fragments up to ½ inch in length and mafic mineral stains occur from 194 to 200 feet; 77.5 feet of core recovered ---- | 82 | 275 |

Table 12.--Log of core hole 3

Cored by rotary with air for carrier

Total depth 300 feet

Completed February 3, 1960

Altitude of land surface 7,170

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Bandelier Tuff | | |
| Tshirege Member | | |
| Unit 6: | | |
| Tuff, light-gray to light-pinkish-gray; fine-grained groundmass with medium- to very coarse-grained quartz and sanidine crystals and fragments; granule-size purplish-brown devitrified pumice; granule to pebble-size medium-brown latite; strongly jointed zone from 23 to 28 feet and 34 to 37 feet; 44.3 feet of core recovered ---------- | 75 | 75 |
| Unit 5: | | |
| No recovery, interpretation from gamma-ray log ---------- | 2 | 77 |

Hole 2-Y, depth 73 feet

Sample is about one-third phenocrysts

Sanidine 22 percent

Quartz 11 percent

Magnetite 1± percent

Pyroxene 0.5± percent

THE fine fraction is devitrified glass composed dominantly of sub-microscopic intergrowths of cristobalite and feldspar.

There are irregular zones around sanidine phenocrysts which may represent an addition of material by gas-phase reaction. In pore spaces, tridymite, sanidine, and slender needles of hornblende have been formed.

At TA-49 the thickness of unit 5 ranges from 0 in large-diameter hole 4-Y (fig. 18) to about 4 feet in a channel intercepted by large-diameter holes in Area 10. Structure contours on top of unit 5 indicate a dip of about 1 degree to the southeast (fig. 13).

Figure 13.--Structure contours on the top of unit $bt_5$ of the Tshirege Member of the Bandelier Tuff, TA-49, Los Alamos County, N. Mex.

## Water-bearing characteristics

Unit 5 was dry at TA-49, and there is little evidence to indicate that the unit has transmitted water in recent times.

Unit 5 is a permeable sand composed mainly of well-sorted quartz and sanidine crystals and crystal fragments. Joints and fractures in the overlying unit 6 are closed and terminate at or near the contact. Only a few fractures transect the sand and continue into unit 4 where most of them are sand filled (fig. 18).

Tuff adjacent to joints and fractures below the sand-filled zone is weathered as much as $\frac{1}{4}$ to 1 inch on each side. Water that caused these weathered joint and fracture surfaces probably moved through the joints and fractures during the deposition of unit 5.

Unit 5 has a permeability of 34 to 39 gpd per square foot (table 17) and should transmit water readily. The abundance of sand-filled and open fractures in the upper part of unit 4 would tend to transmit the water downward rapidly.

## Unit 6

### Physical characteristics

Unit 6 is a light-gray to pinkish-gray rhyolite tuff. It is a moderately welded ash-flow tuff containing phenocrysts of quartz and sanidine that range in size from medium to coarse sand, gray devitrified pumice fragments as much as 3/4-inch in diameter; and gray to light-brown rhyolite and latite rock fragments. Some of the quartz crystals are clear and have well developed crystal faces and some are dipyramidal in crystal form and contain white globular inclusions. Mineralogic analyses indicate a small percent of magnetite and pyroxene and some clay which is probably montmorillonite (table 14). The sand-size mafic minerals are brownish yellow as the result of weathering. Some horizontal sheeting occurs at the outcrops. Curvilinear joints were present in the large-diameter holes and in the outcrops (fig. 14). The

Figure 14.--Outcrop of curved joint face in unit $qbt_6$ of the Tshirege Member of the Bandelier Tuff. North side of New Mexico Highway 4, about 1.5 miles west of the entrance to TA-49, Los Alamos County, N. Mex.

unit unconformably overlies unit 5 and forms cliffs. It caps the mesa at TA-49.

The joints in unit 6 generally are of two types: master joints, THAT have~~ing~~ northerly trends and nearly vertical attitudes, and minor joints (figs. 15, 16, 17, and 18) THAT have~~ing~~ varying trends and dips

Figure 15.--Maps of walls of selected large-diameter holes in Area 1, TA-49, Los Alamos County, N. Mex.

16.--Maps of walls of selected large-diameter holes in Area 2, TA-49, Los Alamos County, N. Mex.

17.--Maps of walls of selected large-diameter holes in Area 3, TA-49, Los Alamos County, N. Mex.

18.--Maps of walls of selected large-diameter holes in Area 4, TA-49, Los Alamos County, N. Mex.

varying from nearly vertical to horizontal.

The master joints are tectonic in origin, and probably are related to major faults of the region, such as the Pajarito fault west of TA-49. Almost every large-diameter hole intersected at least one master joint that is continuous through unit 6, and some that cut through unit 5 into unit 4. Many minor joints terminate at the master joints. Near the surface the master joints are filled with clay, most of which was formed in place by weathering of the tuff, but some of the clay may have washed in from the soil zone above. At depth these joints commonly are open and many have a thin clay plate on both faces of the open joint. Most of these clay plates are altered tuff adjacent to joint faces, caused by water that formerly percolated through the open joints.

The minor joints probably were caused mainly by cooling of the volcanic ash flow, although some of them probably are related to faulting and gentle folding. A nearly horizontal brecciated zone is present in unit 6 about 15 to 20 feet below the surface. The rocks in this zone are broken by numerous irregular minor joints, most of which are open.

Joints could not be projected from a hole to another 25 feet away because of the change in strike and dip and numerous intersections of one joint with others. In some cases it was impossible to match joints on opposite walls of a hole due to the change in strike and intersections. However, interconnection of joints between holes was evident during various experiments in the area conducted by the University of California.

Seven samples from unit 6 of the Tshirege Member of the Bandelier Tuff were analyzed petrographically by C. S. Ross (written communication, July 7, 1960). Ross recalculated the proportions of phenocrysts to represent proportions by weight. The following is a discussion of each of these analyses.

Sample from core hole 1, depth 45.5 feet

Pore space about 30 percent

Phenocrysts about 20 percent by weight

Sanidine 12 percent

Quartz 6 percent

Magnetite 1± percent

Pyroxene 0.5± percent

Groundmass is typical devitrified welded tuff. The devitrification products are very fine grained, but show the typical cristobalite-feldspar structure. Cavities contain radial groups of feldspar and tridymite. The rock contains a few areas of altered andesite.

Sample from core hole 2, depth 65 feet

Typical welded tuff differing from others in no essential way.

Phenocrysts about 24 percent by weight

Sanidine 14 percent

Quartz 7 percent

Pyroxene (clino and ortho) 1 percent

Magnetite 1 percent

Pink, well-rounded zircon

Feldspar and tridymite in cavities

Sample from hole 2-U, depth 52 feet

Pore space about 30 percent

Phenocrysts about 27 percent by weight

Sanidine 20 percent

Quartz 5 percent

Magnetite 1 percent

Pyroxene (clino, dominant; ortho, present)

The groundmass is made up of shards which have been partly devitrified. There is some indication of gas-phase mineralization. Minute minerals, probably tridymite and feldspar, have developed in cavities and feldspar has been deposited on ~~ruins~~ RIMS of sanidine grains. The rock contains very small amounts of altered andesite grains.

Sample from hole 2-H, depth 30 feet

Pore space about 35 percent

Phenocrysts about 20 percent by weight

Sanidine 12 percent

Quartz 4 percent

Magnetite 1 percent

Pyroxene 0.5± percent

Groundmass is in part devitrified shards (feldspar and cristobalite). Brown birefracting clay-like material is probably montmorillonite, 15± percent of the groundmass. This is the only sample in the group which shows any alteration. All other changes are deuteric ones comprising devitrification and gas-phase reaction.

Sample from Hole 2-H, depth 58 feet

Pore space about 30 percent

Phenocrysts about 13 percent by weight

Sanidine 8 percent

Quartz 3 percent

Magnetite 1± percent

Pyroxene 0.5± percent (ortho, sparse; clino, dominant)

Trace of zircon

Much of the magnetite is intergrown with pyroxene. Some altered inclusions of an older andesitic rock are present. Groundmass is devitrified glass shards. Feldspar and tridymite occur in vesicular pore space. A little clay material has developed.

Sample from core hole 3, depth 54 feet

Similar to Area 2 core hole at a depth of 65 feet.

Sample from Hole 3-C, depth 58 feet

Pore space about 30 percent

Phenocrysts about 23 percent by weight

Sanidine 15 percent

Quartz 8 percent

A little secondary growth (gas phase) on the feldspar, but other gas-phase materials are too fine grained to be conspicuous. Groundmass material is devitrified glass. The devitrification products are cristobalite and feldspar. Tridymite and feldspar have developed as gas-phase products in cavities. The groundmass is in part made up of pumice fragments up to 10 mm in diameter which occur as darker colored porous areas.

The thickness of unit 6 at TA-49 ranged from zero near well DT-9, where it has been stripped away by erosion, to 80 feet near core hole 2. An isopach map (fig. 19) indicates that unit 6 is

Figure 19.--Isopach map of unit $bt_6$ of the Tshirege Member of the Bandelier Tuff, TA-49, Los Alamos County, N. Mex.

thickest along the crest of the mesa at TA-49 where it has been eroded the least.

The base of the unit dips about 1 degree in a general southeasterly direction. The eroded upper surface of the unit along the crown of Frijoles Mesa slopes generally eastward at about 150 feet per mile.

## Water-bearing characteristics

Unit 6 was dry at TA-49. Natural moisture content of samples ranged from 0.8 to 8.7 percent by volume (table 17), and porosity ranged from 38 to 54 percent by volume and specific retention from 15 to 27 percent by volume. The higher porosities were found in samples taken near the surface. Vertical permeability of samples ranged from 0.1 to 6 gpd per square foot. The horizontal permeability ranged from 0.2 to 5 gpd per square foot.

Joints in unit 6 near the surface are filled with clay. At depth many of these joints are open. The open joint face may appear unweathered as if jointing has just taken place, or the open joint face may contain a thin layer of clay, which is the product of weathering of the tuff. Tuff adjacent to these clay-plated joint faces are weathered to a light brown in zones from ½ to 5 inches wide parallel to the joint. The weathered zones also occur above horizontal and low angle joints indicating that water moved from the open joint into the tuff by capillarity. (See map of hole 2A, fig. 16.) Water probably percolated through these joints prior to and during the development of the soil.

Percolation of water could occur through open joints where the soil mantle has been stripped off leaving the tuff exposed. Movement would be rapid in the large interconnected joints filling the smaller joints where it would be absorbed by the tuff. Large joints that transect the unit would carry water rapidly into the underlying unit. Movement of water through the unjointed tuff would be slow as indicated by the range of permeabilities of 0.1 to 6 gpd per square foot.

## Soil cover and related material

The mantle rock at TA-49 is characterized by a weathered zone, a water-laid pumice, and a soil zone. The top few feet of unit 6 is composed of broken, partly weathered tuff fragments in a matrix of clay. The weathered tuff grades upward into a clayey soil, except in Areas 2 and 10, where a layer of water-laid pumice occurs between the weathered zone and soil zone.

The weathered zone and soil zone are composed of materials weathered in place from the underlying tuff. The soil zone may contain some material that was washed into the area. The water-laid pumice was washed in during the early stages of development of the soil, and the overlying soil developed from it. The pumice layer occurs only locally and was deposited in a low area on Frijoles Mesa. The brown clay found throughout the soil mantle and associated materials probably is largely montmorillonite (table 14).

## Weathered tuff

The weathered tuff is composed of angular tuff fragments that are slightly weathered in a matrix of brown clay, which contains a few roots. Thickness ranges from a few inches to 4 feet. The base of the weathered zone grades into and is irregularly disconformable with the top of the welded tuff of unit 6. Joints and cracks in the upper part of unit 6 are clay filled. Some clay filling is found in joints as deep as 65 feet below the land surface and some roots occur as deep as 40 feet (figs. 15, 16, 17, and 18).

The nearly impervious clay of the weathered zone virtually eliminates percolation through the zone. Weathered angular tuff fragments usually are isolated in the clay matrix of the zone and contribute little to bulk permeability of the zone.

Where roots in the zone are decayed, some water might move through the weathered zone via openings left by the roots. However, these openings should tend to close as water is introduced owing to the swelling properties of the clay.

## Water-laid pumice

A layer of fairly well sorted, water-worn pumice fragments occurs in Areas 2 and 10 at TA-49. The layer is 2 to 4 feet thick and overlies the weathered tuff zone. The pumice is brownish gray to brown, has a cellular structure of frothy glass, and contains phenocrysts of quartz and sanidine. A few layers of clay, some intermixed brown clay, and roots are present in the pumice layer.

The layer of pumice probably is highly permeable because it is loosely consolidated and the fragments are well sorted and well rounded.

Where the pumice layer has been exposed by construction, as in the ditch adjacent to the road north of Area 2, water could infiltrate rapidly during wet weather. Probably this water would be perched temporarily on the underlying weathered zone. The pumice could also transmit some water laterally along the top of the weathered zone. A very small amount of water may percolate through the weathered zone into the tuff of unit 6; however, most of the water infiltrating the pumice layer probably is returned to the atmosphere by transpiration and evaporation.

## Soil cover

A brown clay soil caps most of the mesa at TA-49. Percentages of various particle sizes in the soil are estimated as follows: 20 percent sand, 30 percent silt, and 50 percent clay. Sand-size particles are crystals and fragments of quartz.

The soil thickness seems to depend on the amount of water available for weathering the underlying tuff. The thickest soil zones are found along shallow, slow-draining ditches, streambeds, and relatively flat areas where water collects and stands. Soil thickness ranges from 0.5 to 9 feet in the shallow test holes drilled for soil-moisture studies. The greatest known thickness of soil (9 feet) at TA-49 occurs on a relatively flat area north of Area 6 (fig. 20).

Figure 20.--Thickness of soil and location of moisture-measurement test holes in TA-49, Los Alamos County, N. Mex.

The weathered zone could not be distinguished from the soil in logging the cuttings during drilling so the soil and weathered zone are logged as a single unit (figs. 21-43). The pumice layer is shown in test holes where it was penetrated in Areas 2 and 10. The thickness of soil is closely related to topographic slope; the soil thins rapidly away from the crown of the mesa, as indicated by the contours on figure 20.

Tubes formed by the decay of roots may transmit water through the soil zone. However, these openings would tend to close as they were wetted because of the swelling properties of the clay.

Percolation of water through the soil zone is small where the soil is relatively undisturbed and would take place only during exceptionally long wet periods, which are rare in the region.

Moisture distribution in the upland soil

and underlying tuff

Twenty-three test holes were drilled for use in studying the soil thickness and distribution of moisture in the soil and underlying tuff of unit 6 of the Tshirege member of the Bandelier tuff. The test holes were located around test areas, roadside drainage ditches, and stream channels (fig. 20). Measurements were made of the moisture content of the soil and tuff at various depths by a neutron-scattering moisture probe. Moisture content determined by the probe ~~appear to be~~ are 1 to 2 percent higher than those made in the laboratory.

Measurements were made at least twice during the period from March to June 1960 and are depicted on graphs of moisture content and lithologic logs (figs. 21 ~~through~~ - 43).

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Figures 21-43.--Graphs of moisture content and lithology in test holes, TA-49, Los Alamos County, N. Mex.

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Moisture content of the soil ranged from 48 percent by volume near the surface in March to 8 percent at depth. The moisture content of the near-surface tuff, WHERE IT WAS covered by a thin soil, ranged from 37 percent by volume to less than 4 percent at depth in test holes in well-drained areas. Moisture content was highest in the upper few feet of soil and tuff in March and April as a result of the late winter snow; it decreased in June due to the higher evapotranspiration rates of early summer. Moisture content of the tuff at depth remained constant in the period March to June except in test hole 1M-3A where an increase of 1 to 3.5 percent by volume was noted between 4 and 13 feet.

## Test holes in well-drained areas

Holes 1M-2; 2M-1 and -2; 3M-1, -2, and -3; 4M-1, -2, -3, and -4; 5M-2; 9M-4; and 10M-1 and -2 are located in well-drained areas and penetrated an average soil or soil and backfill thickness of 3.5 feet (table 20). At the average depth of 4.7 feet in these holes, moisture content decreased from about 30 percent to 10 percent by volume. At the average depth of 8.8 feet, the moisture content decreased further to 5 percent.

The clay soil had retained most of the moisture that fell as snow or rain and the moisture content in the upper part of this soil varied due to evaporation, transpiration, and prevailing weather conditions prior to and during moisture readings. Near the base of the soil zone, no apparent change in moisture content was noted during the period of March to June (figs. 21-34).

The tuff just below the soil zone contained as much as 37 percent moisture by volume. Moisture content in the tuff of unit 6 decreased to less than 10 percent a few feet below the soil. No significant changes in moisture content were noted in the tuff during the period March to June.

The moisture content did not change in the pumice layer during the period March to June. Measurements made in test hole 2M-2 (fig. 23) indicated a moisture content of 25 percent in the pumice layer at 8 feet on May 3, 1960. This anomalously high reading probably is in a thin clay layer in the pumice zone.

Table 20.--Summary of results of moisture measurements in test holes located in well-drained areas

| Test hole | Soil thickness (feet) | Depth at which moisture decreases to 10% by volume (feet) | Depth at which moisture decreases to 5% by volume (feet) |
|---|---|---|---|
| 1M-2 | 1.0 1/ | 2.5 | 7.0 |
| 2M-1 | .5 2/ | 5.5 | 7.0 |
| 2M-2 | 5.5 1,2/ | 6.5 | 9+ |
| 3M-1 | .9 | 2.5 | 4.5 |
| 3M-2 | 2.6 | 6.0 | 9.0 |
| 3M-3 | 7.0 1/ | 3.0 | 14.0 |
| 4M-1 | 1.9 | 3.0 | 7.0 |
| 4M-2 | 1.2 | 4.0 | 13.0 |
| 4M-3 | 3.0 1/ | 4.0 | 7.0 |
| 4M-4 | 2.9 | 4.0 | 10.0 |
| 5M-2 | 3.3 | 6.5 | 9.0 |
| 9M-4 | 12.4 1/ | 9.0 | 12.0 |
| 10M-1 | 2.4 2/ | 3.0 | 5.0 |
| 10M-2 | 4.0 2/ | 6.5 | 10.0 |
| Average | 3.5 | 4.7 | 8.8 |

1/ Backfill composed of soil and tuff.

2/ Soil overlies pumice.

## Test holes in areas THAT receiv~~ing~~e runoff from well-drained areas

Test holes 1M-1 and -3A; 2M-3; 5M-1; 6M-1; and 9M-1, -2, and -3 are located on or near arroyos, drainage ditches, and flat areas THAT DRAIN SLOWLY. ~~of slow drainage.~~ Graphs of moisture readings in these holes are shown on figures 35 ~~through~~ 43.

The average soil thickness of this group of test holes is 5.3 feet (table 21). At an average depth of 9.5 feet, the moisture content decreased to 10 percent by volume, but the moisture content was above 5 percent to depths of more than 19 feet in all but one of the holes. In test hole 1M-1 (fig. 35) the moisture content decreased to 5 percent by volume at 10 feet.

Moisture content determined in the soil penetrated by these test holes varied with evaporation, transpiration, and prevailing weather conditions. No significant change in moisture content of the soil was noted during the period of March to June.

Table 21.--Summary of results of moisture measurements in test holes in areas that receive runoff from well-drained areas

| Test hole | Soil thickness (feet) | Depth at which moisture decreases to 10% by volume (feet) | Depth at which moisture decreases to 5% by volume (feet) |
|---|---|---|---|
| 1M-1 | 4.6 | 6.5 | 10 |
| 1M-3A | 3.2 | 14.0 | 49+ |
| 2M-3 | 5.0 | 8.5 | 19+ |
| 5M-1 | 2.2 | 6.5 | 39+ |
| 6M-1 | 9.0 | 9.0 | 19+ |
| 9M-1 | 6.9 | 19+ | - |
| 9M-2 | 6.9 | 8.5 | 19+ |
| 9M-3 | 4.2 | 4.0 | 19+ |
| Average | 5.3 | 9.5 | - |

No significant change in moisture content in the tuff was noted, except in hole 1M-3A (fig. 20), where THE moisture content increased 1 to 3.5 percent by volume between 4 and 13 feet in the tuff from May 3 to June 30, 1960. Test hole 1M-3A is located on the bank of an arroyo, and the bank is about 5 feet above the bottom of the channel. Construction near test hole 1M-3A caused water to pond 2 to 4 inches deep in the arroyo during wet periods. The thin soil and sand in the channel of the arroyo may have allowed the ponded water to infiltrate downward and laterally into the tuff as shown by the increase of moisture from 1 percent to 3.5 percent at a depth of 4 to 13 feet. Between 13 and 20 feet a small increase in moisture content is suggested, but between 20 and 49 feet the moisture content remained about 6 to 8 percent.

The specific retention of samples of unit 6 ranges from ~~19~~ 15 to 27 percent by volume (table 17). On June 30, 1960, in test hole 1M-3A the moisture content of the tuff ranged from 27.5 percent at 4 feet to 29 percent at 5 feet, suggesting that there may have been some free water in that interval. The increase of 1 to 3.5 percent in moisture content at various depths during the period from May to June may indicate a slow downward movement of moisture in the vicinity of test hole 1M-3A. This indicated movement of moisture into the tuff is brought about by the ponding of water in an area where it was formerly allowed to drain.

## Infiltration from stream flow

Water discharged from well DT-5A during the pumping test was measured frequently in the natural stream channel near test holes 9M-2 and 9M-3 (fig. 20). The results of these measurements and measurements of discharge from the well are shown graphically on figure 44.

Figure 44.--Graph of measurements of flow downstream from well DT-5A as compared to discharge at well during pumping test April 30-May 1, 1960 at TA-49.

Moisture content of soil and rock penetrated in three test holes adjacent to the stream channel was measured on April 30, May 1, 2, 3, and 6, 1960 thus monitoring infiltration from the stream during and after the pumping test. Results of moisture measurements in these three holes, 5M-1, 9M-2, and 9M-3, are shown in figures 39, 42, and 43. From the discharge pipe at the well to near test hole 5M-1 the water flowed in a natural channel partially filled and dammed by drill cuttings from well DT-5A (fig. 20). Downstream from the partial dam to test hole 9M-3 the natural channel is cut into the soil. The bottom of the channel consists mostly of silt, sand, and gravel, but some tuff is exposed.

Pumping started at 10:45 a.m. on April 30. From 10:45 a.m. to 9:15 p.m. flow measurements in the channel at test holes 9M-2 and 9M-3 showed varying flow losses owing to infiltration of water into the drill cuttings, ponding of water near test hole 5M-1, evaporation, and infiltration of water into the tuff and silty clay adjacent to and beneath the stream channel. Flow losses during this first period of the test became progressively less with continued saturation of more of the drill cuttings, stream-bed and stream-bank materials. Flow measurements at test holes 9M-2 and 9M-3 during the period from 9:15 p.m. April 30 to 1:10 a.m. on May 1, 1960, indicated that the flow and losses were at equilibrium. During this time flow loss between well DT-5A and test hole 9M-2 was 1.5 gpm per 100 feet of channel. The flow loss was 0.7 gpm per 100 feet of channel between test holes 9M-2 and 9M-3. The stream banks between test holes 9M-2 and 9M-3 were saturated sometime between about 2 a.m. and 7 a.m. on May 1, 1960, when flow in the channel measured at the test holes became about equal. Flow loss from the well DT-5A to test hole 9M-2 increased to 1.9 gpm per 100 feet of channel from 5:45 a.m. to 8:10 a.m. May 1, 1960.

The greater flow loss in the upper reach of the channel, both during the period of equilibrium and the period of no apparent loss in the lower reach, probably can be attributed to continued but slightly changing percolation into the drill cuttings. Additional vertical infiltration from the pond at the head of the channel may have occurred during this period as air bubbles rose to the surface of the pond at different times during and after the pumping test.

The moisture content measured in test hole 5M-1 did not change during the test. This indicates no lateral movement of water from the pond 22 feet from the test hole (fig. 39) although vertical infiltration from the pond probably occurred.

In test hole 9M-2 at a depth of 1.5 feet in the soil, the moisture content increased 16 percent from April 30 to May 1 (fig. 42). From May 1 to May 6, 1960, capillary return to the surface and evaporation decreased this moisture content by 13 percent. At a depth of 2.5 feet the moisture content increased 3 percent from April 30 to May 2. 1960. Below 2.5 feet there was no significant change in moisture content of the tuff.

In test hole 9M-3 the moisture content increased 6 percent at 1.5 feet from April 30 to May 3, 1960 (fig. 43). At a depth of 2.5 feet the moisture content increased 8 percent during the same period. At a depth of 3.5 feet and below there was no significant change in moisture content.

In the lower reach of the channel it is apparent that there was very little loss of flow after the channel and bank material was saturated. No change in moisture content was detected below 3.5 feet in depth in either of test holes 9M-2 or 9M-3. Any lateral filtration of water from the pond near test hole 5M-1 was not detected indicating that any infiltration would have been downward probably along vertical and near vertical joints into the underlying tuff.

## Recharge to the main aquifer

Data obtained during the investigation indicate that Frijoles Mesa is not part of the ground-water recharge area in the region. Perched water was not found beneath TA-49.

The soil cover on the mesa at TA-49 prevents most of the precipitation from infiltrating into the underlying rocks. The clay-like soil forms an almost perfect seal over the mesa surface and the near-surface joints. This is evidenced by open joints in units 4 and 6 which blow air (figs. 15, 17, and 18) in response to declining barometric pressure. A very low moisture content (table 17) was found in the upper 300 feet of the Tshirege Member. The moisture-meter surveys indicate little or no increase in moisture content below the undisturbed soil zone. Where the soil cover has been disturbed, removed, or water allowed to pond, infiltration into the underlying tuff takes place slowly (fig. 37).

Decreasing flow downstream in perennial streams in Water Canyon to the north and Frijoles Canyon to the south indicates that some recharge may occur beneath the deeper canyons of the Pajarito Plateau. Available data do not show how much of the decrease in flow in the canyons is caused by evapotranspiration and how much is recharge to the bedrock.

The general shape and slope of the piezometric surface (fig. 45)

Figure 45.--Generalized contours on the piezometric surface of the main aquifer, Los Alamos area, New Mexico.

indicate the main source of recharge to the aquifer is west of Frijoles Mesa. The Pajarito fault zone and the slopes of the mountains, which receive relatively high precipitation, probably are part of the main source of recharge.

Some recharge from Frijoles Canyon can be inferred because of the configuration of the contours on the piezometric surface (fig. 45) in that area.

Depth to the piezometric surface of the main aquifer beneath TA-49 ranged from about 1,004 feet below the land surface at DT-9 to 1,142 feet at DT-5A. Much of the difference in water levels in different wells is due to topographic position; however, the altitude of the piezometric surface of the water is almost 40 feet higher in well DT-5A than in wells DT-9 and DT-10, which are respectively 0.8 mile southeast and 0.7 mile east of DT-5A.

The gradient on the piezometric surface is east-southeastward toward the Rio Grande at about ~~89~~ 50 feet per mile (fig. 45).

## Water-level changes

Water-level measurements in well DT-5A (fig. 46) indicate that

Figure 46.--Hydrograph of water levels measured and from recorder charts at well DT-5A, TA-49, Los Alamos County, N. Mex.

the water level was near 1,173 feet below the land surface after the well was developed. One level measured April 30, 1960, is anomalously low owing to residual drawdown after the aquifer test run on the well.

The water level in well DT-9 (fig. 47) declined about 3 feet

Figure 47.--Hydrograph of water levels measured and from recorder charts at well DT-9, TA-49, Los Alamos County, N. Mex.

during the period of drilling of the well. This decline probably represents difference of head in successively deeper water-bearing strata. The water level in 1960 was about 1,003 feet below land surface.

During April a recorder was operated at DT-9 and a microbarograph was operated at TA-49. Changes in water level in the well correlate qualitatively with changes in barometric pressure, but the amplitude of the water-level fluctuations indicates an additional effect that probably is caused by something other than barometric pressure.

Measurements of water level at well DT-10 (fig. 48) show a decline

Figure 48.--Hydrograph of water levels measured and from recorder charts at well DT-10. TA-49. Los Alamos County, N. Mex.

of slightly more than 1 foot during drilling. The change apparently represents a slightly lower head in the lower beds of the Puye conglomerate aquifer. A recorder was operated for 1 week on well DT-10, and daily fluctuations, though barely perceptible, correlate with barometric pressure changes. The water level in this well was about 1,085 feet below land surface during 1960.

## Pumping tests

Pumping tests approximately 16 to 24 hours in length were run on wells DT-5A, DT-9, and DT-10. The pump used for the tests was a 40-horsepower submersible turbine. Discharge was measured by means of parshall flumes set near the well. Measurements of water levels were made with an electrical water-level indicator inside a 1-inch plastic tube banded to the pump. Drawdown and recovery were read directly on a steel tape fastened to the electrical lead for the probe. Recovery of water level after pumping in both wells was analyzed by the method devised by Theis (1935) and later described by Wenzel (1942).

Tests at well DT-5A

Well DT-5A was pumped at a rate of 81 gpm for slightly more than 25 hours April 30 and May 1, 1960. The pump intake was set at 1,287 feet below the land surface for the test. Maximum drawdown during pumping was 14.1 feet indicating a specific capacity for the well of 5.7 gpm per foot of drawdown. Discharged water had a small amount of sand in it during the first 10 minutes of pumping, after which it cleared and remained clear. Temperature of the water pumped was 70°F.

Analysis of water-level recovery after pumping (fig. 51) indicates

Figure 51.--Semilogarithmic graph of recovery of water level in well DT-5A May 1 and 2, 1960, after pumping 25 hours at an average rate of 81 gpm.

a transmissibility, T, of 11,000 gpd per foot for the aquifer here. Approximately 350 feet of the saturated beds penetrated should readily yield water to the well, as indicated by the electrical log. Thus field permeability should be $\frac{11,000}{350}$ or 30 gpd per foot per foot. A comparison of this field permeability with that of well DT-9 suggests that only 20 percent of the potential water-bearing beds is yielding water. As the well was drilled by the rotary method it is inferred that about 80 percent of the saturated interval is plugged with drilling mud. If the well is to be used for water supply the specific capacity probably could be improved further by surging and by use of mud-cutting chemicals.

## Tests at well DT-9

A pumping test was run on well DT-9 May 6 and 7, 1960. The pump was set at 1,117 feet below the land surface, and the well was pumped at 88 gpm--maximum discharge for the pump--for 24 hours.

Maximum drawdown during pumping was 3.95 feet, giving a specific capacity for the well of 22 gpm per foot of drawdown. The discharge was free of sand and sediment throughout the pumping test, and the water temperature was 70° F.

Recovery of water level was analyzed to determine transmissibility of the aquifer in the vicinity of the well (fig. 52). As determined,

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Figure 52.--Semilogarithmic graph of recovery of water level in well DT-9 May 7 and 8, 1960, after pumping 24 hours at an average rate of 88 gpm.

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the transmissibility, T, is 61,000 gpd per foot. ~~From~~ DATA geophysical logs and examination of drill cuttings, ~~it is estimated~~ INDICATE that about 300 feet of a total of 500 feet of saturated aquifer penetrated will readily yield water. Thus, field permeability should be $\frac{61,000}{\cancel{300}\ 300}$, or approximately 200 gpd per foot per foot.

The coefficient of permeability as determined at well DT-9 is more representative of the aquifer in the Santa Fe Group than the transmissibility determined at well DT-5A.

## Tests at well DT-10

An attempt was made (May 1960) to install a pump in well DT-10. An obstruction was found in the well at 1,100 feet, where the casing is reduced with a liner from 12 to 8 inches in diameter. (See table 16.) The obstruction was later swaged out and the pump installed in September 1960.

A 16-hour pumping test was made on well DT-10 September 21 and 22, 1960. The pump was set at 1,185 feet below the land surface, and the average rate of pumping during the test was 78 gpm with a drawdown of 4.8 feet. The specific capacity of the well is 16 gpm per foot of drawdown. The discharge was free of sediment and clear in appearance except during the first minute of pumping, when a foamy, detergent-like substance came out with the water. Some rusty pipe scale was included in the water during the first few minutes of pumping, but this cleared up in a very short time. The temperature of the water during pumping was 67°F, which was 3 degrees cooler than water from the wells DT-5A and DT-9. Well DT-10 is finished in the upper part of the main aquifer, and the lower temperature of water from DT-10 tends to corroborate the stratigraphic analysis that indicates there may be a hydraulic separation between the Puye Conglomerate and the underlying undifferentiated unit of the Santa Fe Group. The cooler water suggests that there may be recharge into the aquifer nearby, possibly along Water Canyon.

Transmissibility of the Puye Conglomerate, as determined from analysis of water-level recovery (fig. 53), is 36,100 gpd per foot.

Figure 53.--Semilograithmic graph of recovery of water level in well DT-10, September 22 and 23, 1960, after 16 hours of pumping at an average rate of 78 gpm.

~~It is estimated~~ DATA from geophysical logs and examination of the drill cuttings INDICATE that about 200 feet of the saturated section penetrated by DT-10 readily yields water to the well. Therefore, field permeability is about 180 gpd per foot per foot, a figure that compares favorably with the field permeability of 200 determined at well DT-9.

## Velocity of ground-water movement

Velocity of flow in an aquifer can be computed by the following equation:

$$V \text{ (in feet per day)} = \frac{PI}{p}$$

wherein:

P = field permeability, gpd per foot per foot (gallons converted to cubic feet)

I = gradient, feet per foot

p = porosity of the aquifer, percent

The average permeability of the aquifer, as determined by pumping tests at wells DT-9 and DT-10, is approximately ~~190~~ 180 gpd per square foot, which is more representative of the aquifer than the value obtained at DT-5A. The gradient on the piezometric surface between wells DT-5A and DT-10 is about ~~60~~ feet per mile. Porosity is estimated to be 25 percent, an average value based on porosity determinations for many materials of the same character as those common in the Santa Fe Group. If these values are substituted in the above equation, the velocity is $\frac{180}{(7.48)\ 0.25} \cdot \frac{60}{(5{,}280)} = 1.098$ feet per day, or roughly 400 feet per year.

V =

## Quantity of water moving through the aquifer

The quantity of ground water passing through a given cross-sectional area of the aquifer can be estimated from the equation

$$Q \text{ in gpd} = PIAp$$

where A is the cross-sectional area of the aquifer. The average estimated thicknesses of beds readily yielding water to the deeper wells DT-5A and DT-9 are 350 and 300 feet, respectively, or, averaged together, 325 feet. The width of the affected area beneath TA-49 at right angles to the east-southeast direction of movement of the ground water is about 2,000 feet. Then:

$$Q = (180) \cdot \frac{60}{5{,}280} \cdot (325)\ (2{,}000)\ 0.25$$

$$= 331{,}440 \text{ gpd}$$

or approximately 370 acre-feet per year passing through the cross-section of the aquifer beneath the test areas at TA-49.

## Quality of water

Water samples were collected while wells DT-9 and -10 were being drilled to determine whether there was a change in chemical constituents at depth (table 22). A single field conductance was made on a sample from well DT-5A at the end of the development period.

Analysis of water from various depths in wells DT-9 and -10 indicates a decrease in specific conductance in both wells and a decrease in carbonate concentration with depth in well DT-10. The pH of water in both wells also decreases with depth. This may indicate contamination by drilling mud of the water sampled. The analyses, though possibly contaminated, indicate that there is a small difference between chemical composition of the water within the Tschicoma Formation and members of the Santa Fe Group.

Water samples were collected at the end of the pumping tests on wells DT-5A, -9, and -10, and a single bailer sample was collected from well DT-10 upon completion. Water from the three wells is soft and is low in dissolved solids (table 23). The specific conductance is low, and the pH is near 7. Calcium, magnesium, and sodium are the principal cations, while more than 90 percent of the anions are bicarbonate. The silica content is high. The high silica concentrations are typical of water that is recharged or moves through extrusive felsic rocks, such as those which occur in the Los Alamos area.

The water from wells DT-5A, 9, and 10 is similar to water found in the test and supply wells in the area. The water is of good quality for domestic and most industrial use, but the silica scale produced when the water is heated may be objectionable for certain industrial uses.

Radiochemical analyses from wells DT-5A, 9, and 10 are shown on table ~~28~~ 23. The analyses indicate that the concentration of radionuclides is well below the tolerance limits and the data are included for future background study.

Table 21.--Partial chemical analyses of water samples from deep wells - Continued

| Well No. | Depth of well (feet) | Date of collection | Stratigraphic unit | Temperature (°F) | Silica ($SiO_2$) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Hardness as ($CaCO_3$) Calcium and magnesium | Specific conductance (micromhos at 25° C) | Specific conductance, measured in field (micromhos at 25° C) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DT-9 | 1,220 | 2- 6-60 | Santa Fe Group | | 64 | 110 | 0 | 38 | 299 | | 8.2 |
| | 1,286 | 2- 9-60 | Continued | 49 | 65 | 112 | 1 | 41 | 326 | | 8.3 |
| | 1,327 | 2-16-60 | | 68 | 56 | 88 | 0 | 28 | 191 | | 7.7 |
| | 1,501 | 2-20-60 | | 68 | 60 | 78 | 0 | 33 | 155 | 185 | 7.5 |
| | 1,501 | 5- 7-60 | | 71 | | | | | | 145 | |

Table 21.--~~Partial~~ chemical analyses of water ~~samples~~ from deep wells at TA-49, Los Alamos County, ~~New~~ Mex~~ico~~

(Analyses by U.S. Geological Survey, Quality of Water Branch, Albuquerque, N. Mex.

(Constituents in parts per million except as otherwise indicated in column head.)

| Well No. | Depth of well (feet) | Date of collection | Stratigraphic unit | Temperature (°F) | Silica ($SiO_2$) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Hardness as ($CaCO_3$) / Calcium and magnesium | Specific conductance (micromhos at 25° C) | Specific conductance ~~measured in~~ field (micromhos at 25° C) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DT-5A | 1,821 | 3-25-60 | Santa Fe Group | | | | | | | 420 | |
| DT-10 | 1,120 | 3- 8-60 | Puye conglom- | 65 | 54 | 202 | 15 | 103 | 617 | 520 | 8.9 |
| | 1,221 | 3- 8-60 | erate | 66 | 41 | 157 | 3 | 56 | 506 | | 8.4 |
| | 1,248 | 3- 8-60 | | 67 | 43 | 154 | 9 | 77 | 488 | 400 | 8.7 |
| | 1,256 | 3- 9-60 | | 68 | 37 | 160 | 5 | 67 | 529 | 370 | 8.4 |
| | 1,338 | 3-11-60 | | 67 | | | | | | 290 | |
| | 1,424 | 3-11-60 | | 66 | | | | | | 290 | |
| | 1,430 | 3-13-60 | | 65 | | | | | | 115 | |
| | 1,430 | 3-13-60 | | 65 | | | | | | 180 | |
| DT-9 | 1,048 | 2- 2-60 | Santa Fe Group | 68 | 68 | 98 | 0 | 32 | 260 | | 8.2 |
| | 1,060 | 2- 3-60 | | | 72 | 76 | 0 | 28 | 157 | | 8.0 |

## Age of ground water in the principal aquifer

Tritium content in ground water sometimes can be used to determine the age of the water (von Buttlar and Libby, 1955, and von Buttlar and Wendt, 1958) and, with sufficient sampling, sometimes can be used as a tracer to obtain direction and rate of movement of ground water. The rate of movement of ground water may be determined by referring anomalously high tritium concentrations in ground water to recharge occurring soon after the hydrogen-bomb experiments. At the time of the explosion, large quantities of tritium were released into the atmosphere and returned to the earth's surface in precipitation. The first hydrogen-bomb experiment, in November 1952, released some tritium to the atmosphere, but the first experiment to release large quantities was in March 1954. Several series of tests were made between March 1954 and October 1958 (Telegadas, 1959).

Samples of rainfall at Los Alamos taken in June 1954, after the second hydrogen-bomb explosion, had 1,160 to 1,550 T.U. A tritium unit (T.U.) is defined as one atom of tritium in $10^{18}$ atoms of hydrogen. A sample collected Feb. 7, 1954, from Rito de los Frijoles, a stream that drains an area typical of recharge area to the north, at Bandelier National Monument, had 27.2 ±0.4 T.U. (von Buttlar and Libby, 1955) and is thought to be representative of rain and snow that fell on the recharge area between hydrogen-bomb explosions 1 and 2, in November 1952 and March 1954, respectively. Water from this era of recharge may appear in wells in TA-49 in about 1975 as water having an approximate tritium concentration of about 7 T.U. Average pre-bomb tritium content in precipitation is thought to have been about 8 T.U., based on analyses of Chicago precipitation by Kaufman and Libby (1954) and von Buttlar and Libby (1955). The only pre-hydrogen-bomb tritium analyses available are those made at Chicago. Assuming that water in the aquifer at TA-49 has not been enriched with tritium by local recharge, the age of water in the aquifer can be determined from samples collected from deep test wells, provided the samples contain detectable quantities of tritium.

Three samples of water from two of the deep test wells contained detectable quantities of tritium. As the half life of tritium is 12.26 years, the ages of samples could be computed. The following table includes the results of tritium analyses and computed ages of samples:

| Well No. | Date collected | Date analyzed | Depth of well when collected | Tritium units (T.U.) | Computed ages of samples (years) |
|---|---|---|---|---|---|
| DT-5A | 5- 1-60 | 11--60 | 1,821 | 2.6 | 19.9 or 20 |
| DT-9 | 2-16-60 | 11--60 | 1,325 | 3.8 | 13.1 or 13 |
| DT-9 | 5- 7-60 | 11-60 | 1,501 | 3.5 | 14.6 or 15 |

The significance of apparent differences in age cannot be fully assessed; however, it seems reasonable that water deeper in the aquifer moves more slowly and is actually older. Probably both samples that indicate relatively younger water are mixtures of water near the top of the zone of saturation with deeper water. More hydrologic data would be needed to determine which zones contribute most of the water in order to evaluate differing concentrations with depth in the aquifer.

Moreover, some young water may be added to the aquifer by local recharge from canyon sources such as Water Canyon. Thus, samples may be mixtures of a very small amount of local recharge water with older water coming from major areas of recharge on the mountain slopes to the west.

The Pajarito fault zone presumably is the most likely principal recharge area, as recharge should readily percolate downward here through fractured rock. The fault zone is about 3.7 miles, or 20,000 feet, up the ground-water gradient from TA-49. Assuming that the fault zone and vicinity are the main area of recharge and that the three samples analyzed are undiluted and unenriched water from the recharge area, then

$$\frac{\text{20,000 feet (distance to recharge area)}}{\text{15.9 years (average age of samples analyzed)}} = \text{1,260 feet per year,}$$

or about 1,300 feet per year is the approximate velocity of ground-water movement. This computed velocity is considerably greater than the velocity (400 feet per year) computed from pumping-test data and gradient of the piezometric surface. This line of reasoning does not allow any appreciable period of time for the movement of water from the surface in the recharge area down to the aquifer, which probably is a valid concept if open fractures are the route of downward movement.

The approximate location of the recharge area can be determined by using these age-of-water data in another way:

$$\text{400 feet per year} \times \text{15.9 years} = \text{6,300 feet}$$

Thus, a part of the area of recharge may be nearer to TA-49 than the Pajarito fault zone, probably along Water Canyon and other nearby canyons east of the Pajarito fault zone. Relegating any appreciable time to vertical movement in the zone of aeration would have the effect of making the recharge area closer to the point of sampling or increasing velocity of movement in the zone of saturation.

## Conclusions and suggestions

Data obtained from the large-diameter holes indicates that little, if any, recharge to the ground water presently occurs at Frijoles Mesa. Clayey soil and clay filling the near-surface parts of joints are a barrier to infiltration of water into joints. The effectiveness of this impervious seal is indicated by blowing of air from open joints at depth in response to declining barometric pressure. At some time in the past, joints in the Bandelier Tuff have carried percolating water, as indicated by alteration of joint faces in the rock. This percolation presumably occurred before the soil mantle was developed.

The moisture readings in the test holes indicate that water rarely infiltrates the mesa surface to depths greater than the thickness of the soil and that a soil cover as much as 2 feet thick seemingly prevents natural infiltration to the underlying bedrock. Locally, where the soil cover is thin or absent and in some places on the mesa that receive runoff from well-drained areas, some small amount of infiltration into the tuff does occur.

Moisture determinations made in test holes adjacent to a natural channel that carried water discharged from well DT-5A during a pumping test indicate that infiltration took place laterally into the soil and related weathered materials. Moisture measurements in the holes made after flow stopped in the channel indicate that water that had moved laterally from the stream was returned to the surface by capillarity and evaporated. Some water was lost continually from a disturbed part of the channel in the upper reach throughout the period of flow. A part of this loss could have gone downward into the tuff.

The large loss of drilling mud and water into the 930 feet of Bandelier Tuff penetrated by wells DT-5 and DT-5A probably was into open joints. Data are not available to determine whether the water lost in drilling the two wells moved downward through the Bandelier Tuff and into the Puye Conglomerate. It is likely that this liquid is entrapped in the labyrinth of interconnected joints and is slowly being absorbed by the tuff adjacent to the joints.

No perched water was observed in the interval between the mesa surface at TA-49 and the main zone of saturation at a depth of somewhat more than 1,000 feet. The absence of perched water and the large bulk permeability of the Bandelier Tuff indicate that it would transmit water rapidly. Water that has access to the tuff and joint systems, if in sufficient quantities, will move with ease almost vertically downward into the Puye Conglomerate and eventually into the zone of saturation.

Soil materials for sealing abandoned test areas are available on the mesa. Soil for sealing purposes should be obtained in places as far away from testing areas as possible because wherever natural soil is scalped, chances are increased for infiltration of water into the tuff. Adequate drainage on the mesa should be maintained to prevent infiltration from ponded water.

Recharge to the ground water from Frijoles Mesa is very small or nonexistent; thus, no contaminants in solution are likely to be carried to the ground water beneath TA-49. However, if contaminants should reach the main ground-water body, several conditions, mainly hydrologic, exist that tend to decrease hazards resulting from such contamination:

1. Presently no ground water is used downgradient in the Los Alamos area from TA-49. The Rio Grande, into which the ground water is naturally discharged, is the nearest point of hazardous contamination of water supplies.

2. Some dilution of the contaminated water would occur in the aquifer and further dilution would occur in the Rio Grande as the contaminants were slowly discharged into it.

3. At the slow migration rate of ground water in the Los Alamos area, it would take about 80 years for contaminants to move from a point in the aquifer beneath TA-49 to the Rio Grande.

4. Ion exchange or adsorption of dissolved contaminants onto materials through which the contaminated water passes will reduce the concentration of radioactive contaminants. This was investigated by the Health Division of the Los Alamos Scientific Laboratory for the upper part of the Bandelier Tuff at TA-49. The aquifer materials also presumably will absorb some of the contaminants.

## Suggested continuing study

Water samples for radiometric analysis should be collected annually from wells DT-5A, 9, and 10 to determine whether contamination is taking place. If well DT-5A could be pumped steadily and the water used at TA-49, it would be advantageous to monitoring because a slightly greater part of the aquifer could be sampled in this way. Samples from the other wells could be obtained with a bailer. The well that is pumped should be provided with an air line to record its water level and a measuring tube (about 1 inch in diameter) should be provided also so that air-line recordings can be checked periodically by direct measurement. A continuous water-level recorder should be installed in the well DT-9. The wells that are not used for water supply should be pumped once every 5 to 10 years for a period of 1 to 3 months and sampled for radiochemical analyses.

Moisture readings should be made in the test holes four times each year to determine whether there is infiltration of water. The frequency of moisture readings can be decreased in some of the holes when data indicate that the results are not significant.

Compacted soil should be used to seal the abandoned test areas, and the casings of the core holes in these areas should be extended through the soil cover. The core holes could then be used for measuring the moisture content of the compacted soil cover and underlying tuff and for gamma-ray logging.

It would be informative to sink an angular drift to a point a few feet beneath a large-diameter hole and inject water into the large-diameter hole to sample the water filtering into the angular drift by means of porous cups or drip-catching jugs. Injection water could be spiked with a radioactive tracer. Radiometric analyses of water samples should indicate whether contaminants will pass through tuff or joints in the tuff.

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## Appendix

Data contained herein was collected during the course of investigation of TA-49, Los Alamos County, N. Mex. It is not specifically considered in this report and is appended for possible use by future investigators.

Table 24.--Particle-size distribution in percent by weight for samples from TA-49, Los Alamos County, N. Mex.

| Lab. No. | Source of sample | Depth (feet) | Stratigraphic unit in Tshirege Mbr. | Diameter of particles in millimeters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand | | | | | Gravel | | |
| | | | | <0.004 clay | 0.004-0.0625 silt | 0.0625-0.125 v. fine | 0.125-0.25 fine | .25-.5 medium | .5-1 coarse | 1-2 v. coarse | 2-4 v. fine | 4-8 fine | 8-16 medium |
| 60NM10 | 4-U | 61 | 5 | 2.7 | 10.2 | 7.0 | 20.9 | 27.0 | 25.2 | 6.4 | 0.5 | 0.1 | - |
| 59NM199 | 4-A | 66 | 5 | 3.9 | 11.0 | 7.3 | 9.6 | 17.9 | 24.3 | 20.1 | 4.9 | .8 | 0.2 |
| 60NM24 | Beta | 10 | 1B | 30.0 | 11.4 | 3.2 | 6.8 | 24.2 | 14.6 | 9.8 | - | - | - |
| 60NM25 | Beta | 65 | 1B | 8.0 | 35.0 | 11.9 | 14.3 | 12.5 | 14.6 | 2.8 | .7 | .2 | - |
| 60NM26 | Beta | 135 | 1B | 42.7 | 20.2 | 9.7 | 13.1 | 6.3 | 4.4 | .6 | .4 | 1.3 | 1.3 |
| 60NM27 | Beta | 180 | 1B | 13.0 | 28.8 | 8.7 | 10.4 | 12.5 | 16.9 | 6.0 | 3.1 | .6 | - |
| 60NM28 | Alpha | 175 | 3 | 3.9 | 24.3 | 10.4 | 11.4 | 14.6 | 16.4 | 19.0 | - | - | - |

Table 25.--Pore-size distribution and soil-moisture tension of samples from TA-49, Los Alamos County, N. Mex.

| Lab. sample No. | Source of sample | Depth (feet) | Stratigraphic unit | Pore-size distribution (cm of water) | | | | | Moisture content at 1/3 atmosphere tension (percent) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 15 | 30 | 60 | 150 | |
| 60NM6 | 2-O | 30 | $Qbt_6$ | | | - | | | 40.05 |
| 60NM7 | 1-A | 30 | $Qbt_6$ | | | - | | | 40.86 |
| 60NM1 | 4-U | 40 | $Qbt_6$ | 45.80 | 43.81 | 41.54 | 41.88 | 40.46 | 38.74 |
| 60NM9 | 2-F | 56 | $Qbt_6$ | | | - | | | 29.60 |
| 60NM8 | 1-A | 58 | $Qbt_6$ | | | - | | | 40.55 |
| 60NM2 | 4-U | 60 | $Qbt_6$ | 48.45 | 46.18 | 44.06 | 44.72 | 43.41 | 42.62 |
| 60NM10 | 4-U | 61 | $Qbt_5$ | | | - | | | 4.49 |
| 60NM3 | 4-U | 67 | $Qbt_4$ | 39.51 | 38.22 | 40.09 | 39.18 | 22.30 | 20.68 |
| 60NM5 | 4-U | 82 | $Qbt_4$ | 36.95 | 34.70 | 33.11 | 33.17 | 29.96 | 24.54 |
| 60NM4 | 4-U | 104 | $Qbt_4$ | 33.57 | 32.23 | 30.38 | 30.36 | 31.22 | 29.14 |

Table 2L.--Reconnaissance notes for large-diameter holes in areas 1, 2, 3, 4, and 10, TA-49, Los Alamos County, N. Mex.

Area 1

Hole 1-A Diameter - 6 feet

| Depth (feet) | |
|---|---|
| 0-2 | Soil |
| 2-15 | Vertical joint in west wall is 2 inches clay filled. In southwest wall vertical joint is 2 inch clay filled. Northeast wall has vertical joint 1/8 inch clay filled. South wall has vertical joint $\frac{1}{4}$ inch clay filled. North wall has two joints that are $\frac{1}{4}$ inch clay filled. |
| 15 | Northeast wall has horizontal joint open $\frac{1}{4}$ inch. |
| 35 | Vertical joints are open $\frac{1}{4}$ to $\frac{1}{2}$ inch. Large fracture zone on northeast wall has joint openings $\frac{1}{4}$ to 1 inch. |
| 50 | Fracture zone on east wall contains joint openings $\frac{1}{4}$ to [illegible] inch. |
| 55 | Joints on north and west walls join at apex and are open $\frac{1}{4}$ inch. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 1 - Continued

Hole 1-J

| Depth (feet) | |
|---|---|
| 0-3 | Soil |
| 3 | Near vertical joint on southeast and southwest walls meet in apex down hole at 28 feet. |
| 5 | Horizontal joint is open 1/8 inch. |
| 15 | Low dipping joint system around hole has openings up to $\frac{1}{2}$ inch. |
| 35 | Apex of near vertical joint on northeast wall. Joint is open 1/8 inch. |
| 52 | Flat-lying joints are open 1/8 to $\frac{1}{4}$ inch. |

Table 20.--Reconnaissance notes for large-diameter holes - Continued

Area 1 - Continued

Hole 1-P

| Depth (feet) | |
|---|---|
| 0-2 | Soil, 2 feet thick on north wall, thins to 6 inches on the south wall. |
| 2 | Two vertical joints on north wall are 1 foot apart and contain $\frac{1}{4}$ inch of clay filling. East wall shows vertical joint which is 1 inch clay filled. Vertical joint on south wall is 1/16 inch clay filled. Vertical joint on west wall is complement of joint on north wall. |
| 4 | On northeast wall apex of joint dips steeply to the southeast. |
| 16 | Fracture zone. |
| 25 | Apex with limbs upward of two joints which are open 1/8 inch in places on the north and west walls. Well-developed, flat-lying joint is open 1/8 to $\frac{1}{4}$ inch. |
| 30-35 | Flat-lying joints which are open 1/8 to $\frac{1}{4}$ inch. |
| 40 | Vertical joints on north and northeast walls split and die out. |
| 50 | Well-developed joint system on north wall is open $\frac{1}{4}$ to $\frac{1}{2}$ inch. |

Table 2~~x~~.--Reconnaissance notes for large-diameter holes - Continued

Area 1 - Continued

Hole 1-T

| Depth (feet) | |
|---|---|
| 0-3 | Soil, flat-lying joints under soil zone are clay filled. |
| 3 | Vertical joint on northwest wall is $\frac{1}{4}$ inch clay filled. Northeast wall shows a vertical joint which is 1 inch clay filled with white altered tuff $\frac{1}{4}$ inch on each joint face. Vertical joint on south wall is 1 inch clay filled. |
| 17 | Joint system exposed on east wall contains joints that are open 1/8 to $\frac{1}{4}$ inch. |
| 21 | Flat-lying joints extending around hole are open $\frac{1}{4}$ inch locally. |
| 30 | Vertical joint on south wall is open $\frac{1}{4}$ inch. |
| 40 | Apex of joint on northeast wall dips steeply to southeast and is open $\frac{1}{4}$ inch. |
| 58 | North-northeast wall contains joint which is open 1 inch. Trace of joint across hole on west wall is open $\frac{1}{2}$ to 1 inch. This is the same joint that has an apex at 40 feet. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 1 - Continued

Hole 1-W

| Depth (feet) | |
|---|---|
| 0-3 | Soil |
| 3 | Northwest wall has vertical joint $\frac{1}{4}$ inch clay filled. Vertical joint on northeast wall is $\frac{1}{4}$ inch clay filled. Vertical joint on east wall is $\frac{1}{4}$ inch clay filled. Southwest wall has vertical joint 1/8 inch clay and root filled. |
| 10 | Southeast wall shows vertical joint with 1 to 3 inches of white alteration material in joint. Joint continued down hole to a depth of 25 feet. |
| 15 | Intersection of curved joint on west wall and joint on northwest wall. Intersection of joint is open $\frac{1}{4}$ to $\frac{1}{2}$ inch. Joint continues down hole on northwest wall. Flat-lying joint is open 1/8 inch. |
| 25-40 | Joint on southeast wall is open 1/8 inch passing through as intensely fractured zone. Joint on east wall is open 1/8 inch passing through intensely fractured zone. |

Note: Below 40 feet most joints are open slightly.

Table 2~~1~~.--Reconnaissance notes for large-diameter holes - Continued

Area 2

Hole 2-D Diameter - 6 feet; depth - 57 feet

| Depth (feet) | |
|---|---|
| 0-1 | Soil |
| 1-5 | Pumice, water-laid. |
| 5-6 | Weathered zone, tuff fragments in matrix of brown clay. |
| 15 | Joints on northeast and west wall are clay filled 1 to $1\frac{1}{2}$ inches. |
| 20 | Horizontal joints around hole are clay filled $\frac{1}{4}$ to $\frac{1}{2}$ inch. |
| 23 | Joints mentioned at 15 feet come to apex on southwest wall, strike southeast and dip steeply southwest, and are 1 inch alteration filled. |
| 27 | Joint on north side of hole is open and clay filled locally up to $\frac{1}{4}$ inch. |
| 32 | Joint on south wall terminates against a joint system which dips to the northwest at about 30 feet. |
| 42-43 | Apex of joints mentioned at 27 and 32 feet strike east and dip steeply southward. Hole is strongly jointed. Northeast and southeast walls have large plucked zones. Joints on northeast wall are flat to steeply dipping northward and are open 1/8 to $\frac{1}{4}$ inch with some alteration lining. |
| 43-57 | Northern half of hole has many joints striking northwest and dipping steeply to the northeast. |

Table 24.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-F Diameter - 6 feet; depth - 58 feet

| Depth (feet) | |
|---|---|
| 0-1.4 | Soil, containing roots. |
| 1.4-5 | Pumice, water-laid, some clay, roots up to 3/4 inch thick. Bottom of pumice zone dips slightly to the north. |
| 5-7 | Weathered zone, tuff fragments in matrix of brown clay. |
| 16 | Northeast wall has several joints that are vertical, strike north, and are clay filled $\frac{1}{4}$ inch. |
| 16-18 | Numerous flat-lying joints are clay filled up to 1/8 inch. |
| 20 | Northeast wall has north-northeast striking joints that dip steeply to the northeast and are clay filled 1/8 to $\frac{1}{4}$ inch. Large medium gray devitrified pumice fragments up to 3 inches in length are found to a depth of 22 feet. |
| 23 | Irregular joints strike east-west and dip about 45° to the north. These joints circle the hole and are open locally up to $\frac{1}{4}$ inch. |
| 25 | Joints on southeast wall are clay filled. West wall contains irregular joints that are open 1/8 to 3/8 inch. |
| 28 | Hole diameter now 6.4 feet. |
| 29 | Flat-lying joints are open 1/8 to $\frac{1}{4}$ inch. |
| 34 | Irregular joints on north wall are open 1/8 to $\frac{1}{4}$ inch. |

Table ~~25~~ 26.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-F - Continued

| Depth (feet) | |
|---|---|
| 35-38 | System of low angle joints around the hole. Joints strike east-west and are open locally up to 1/8 inch. |
| 40-58 | On the north side of hole is system of joints striking northwest, dipping steeply east that are open $\frac{1}{4}$ to $\frac{1}{2}$ inch. There is a large plucked zone on the north side of the hole from 49 to 58 feet. Hole is belled to 7 feet in diameter from 52 to 58 feet. |

Table 2~~5~~.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-H Diameter - 6 feet; depth - 58 feet

| Depth (feet) | |
|---|---|
| 0-1 | Fill, broken tuff. |
| 1-2 | Soil, clayey, brown. |
| 2-5 | Pumice, water-laid, about 3 feet thick on north and west wall, thins to 1 foot on southeast wall. |
| 5-7 | Weathered zone, tuff fragments in a brown clay matrix. |
| 7 | North-northeast striking joint dips to the west 80° to 85° and is clay filled 1 inch. |
| 13 | West-northwest striking joints on northwest side of hole dip with a slight angle and are clay filled. |
| 18-22 | East-west striking joints are clay and root filled up to $\frac{1}{4}$ inch. Apex on north side of hole. |
| 22-26 | East-west striking joints dip to the northwest at 15° to 30° and are open 1/8 to $\frac{1}{2}$ inch, clay lined. |
| 30-34 | Several west-northwest striking joints dip 45° to the north and are clay filled 1/8 inch. |
| 35-42 | Intersecting near flat-lying joint systems circle the hole. Above the joints tuff is light pinkish brown and is evidently altered by water. Below the joints the tuff is light gray. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-H - Continued

| Depth (feet) | |
|---|---|
| 48 | East-west striking joint dips 80° to 85° north and is open 1/8 to $\frac{1}{4}$ inch. |
| 50-58 | Northwest striking joint is tangent to hole on northeast wall causing bad pluck from 50 to 58 feet. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-J  Diameter - 6 feet; depth - 58 feet

| Depth (feet) | |
|---|---|
| 0-2 | Fill, broken tuff with about 6 inches of brown clayey soil near bottom. |
| 2-5 | Pumice, water-laid. |
| 5 | Northwest striking joint on west wall of hole caused pluck out. |
| 11 | Broken zone on south wall of hole. |
| 11-19 | Light gray tuff contains dark gray devitrified pumice fragments up to $1\frac{1}{2}$ inches in length. |
| 22-29 | Northwest striking joint on west wall of hole is clay and root filled. |
| 33-36 | East-west striking joint dips north at 20° to 30° and is open up to $\frac{1}{4}$ inch. Northwest striking joint now striking north and drifts to center of hole at bottom, dipping about 80° east. Light pink alteration in joints that are open locally. |
| 41 | Northwest striking joint system dips 15° to 30° north and is open up to 1/8 inch. |
| 45-58 | Small pluck out on north wall between 45 and 58 feet. Bottom of hole is in relatively unjointed rock. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-L Diameter - 6 feet; depth - 58 feet

| Depth (feet) | |
|---|---|
| 0-2 | Soil |
| 2-10 | On north wall a northeast striking vertical joint is clay filled $\frac{1}{2}$ inch to a depth of 10 feet. Below 10 feet this joint is open. North-northwest wall shows vertical joint that is $\frac{1}{4}$ inch clay filled. Southwest wall shows vertical joint striking northeast that is 2 inches, clay filled. At 10 feet there is a system of flat-lying joints. |
| 20 | System of flat-lying joints are open locally up to 1/16 inch. |
| 34 | On north wall a joint is open $\frac{1}{4}$ inch with pink weathered tuff on each side forming clay lining of joint surface. Triangular pluck hole on south wall. |
| 36 | Triangle-shaped pluck hole on east wall. |
| 44 | Joints are clay and root filled. |
| 54 | Most joints are closed. Some are open locally up to 1/16 inch. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-0 Diameter - 6 feet; depth - 38 feet

| Depth (feet) | |
|---|---|
| 0-1 | Soil, brownish, clayey. |
| 1-5 | Pumice, water-laid, pieces up to 1 inch in length, subrounded with some clay interlayered. Base of pumice dips slightly to the northeast. |
| 5-7 | Weathered zone composed of large, angular pieces of tuff in a matrix of brown clay. |
| 7-15 | Master joint on northeast and south walls striking north-northeast, dipping steeply, is clay filled $\frac{1}{2}$ inch with a few roots. Joint on northwest wall strikes north-northwest and is 1 inch clay filled but is open locally. Joint on west-southwest wall strikes north and is $\frac{1}{4}$ inch clay filled. On south wall is a system of vertical joints striking east-west. |
| 15-21 | A flat-lying joint dips at a low angle to the north-northwest and is open up to 1/8 inch. Several minor joints terminate against this flat-lying joint. At 17 feet tuff appears more dense than above. |
| 23-26 | Badly broken zone dipping slightly north-northeast. |

Table 24.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-C - Continued

| Depth (feet) | |
|---|---|
| 31 | Master joint on northeast wall is clay filled and locally open ½ inch. On west wall a system of vertical joints originates in a broken zone at 26 feet. Joints in system strike north-northeast and are clay filled and open locally up to ¼ inch. |
| 37 | Pluck out of master joint on northeast wall where joint is open 3/4 inch; opening extends 1.5 feet into the face of the hole. Tuff contains devitrified pumice fragments up to 1 inch across. |
| 40 | Joint on northeast wall, dipping moderately to the north, and connecting joint on west wall with master joint. |
| 41-50 | Large triangular pluck from intersecting joints on southwest wall. Master joint on northeast wall is now hair line. West-northwest striking joint, complement of plucked out joint at 40 to 41 feet. This joint has roots and brown clay at 45 feet. |
| 54 | Apex of north-northwest striking joint on west wall. Rock has considerable amounts of granule to pebble-size devitrified pumice fragments. |
| 55 | Joint on northwest wall dips moderately to southeast. Apex is at 55 feet. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-S Diameter - 6 feet; Depth - 58 feet

| Depth (feet) | |
|---|---|
| 0-3 | Soil, clayey, brown. |
| 3-5 | Pumice, water-laid. |
| 5 | Vertical joint north-northeast wall clay filled 1/32 inch. Vertical joint on southwest wall is ½ inch clay filled. Vertical joint on west wall is 1 inch clay and root filled. |
| 17 | Joint system, clay filled triangular pluck 8 inches across. |
| 22 | East wall shows joint striking northeast. |
| 24 | Vertical joint on west wall becomes irregular with various branches that are clay filled. |
| 32-35 | Vertical joint on west wall splits and dies out at 35 feet. Joints are clay and root filled 1/8 inch. Horizontal joints at 35 feet are open up to ¼ inch. |
| 40 | Joint system about 1 foot east of north line is open ¼ inch. Small irregular closed fractures are found at various places around hole. |
| 49-57 | Joints and pluck on east wall. Southwest wall has vertical joint. Joint trending east dips 45° west. Joints are clay filled and open locally up to 1 inch. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-V Diameter - 6 feet; depth - 58 feet

| Depth (feet) | |
|---|---|
| 0-4 | Soil, brown with pumice pockets on southwest wall. |
| 4-5 | Weathered zone, tuff fragments in a matrix of brown clay. |
| 10 | Master joint on northeast wall strikes south-southwest and is 1 inch clay filled. |
| 9-15 | Vertical joint tangent to north-northeast wall strikes east-southeast and intersects master joint. Joint on southwest wall strikes northwest and causes pluck at 15 feet, where joint is tangent to hole. |
| 18 | Flat-lying brecciated zone around hole. Devitrified pumice fragments in tuff are as much as 1 inch in length. Joint on southwest wall strikes northeast and is open $\frac{1}{2}$ inch. |
| 28 | Southwest striking joint intersects tangential joint on northeast wall. Southwest wall has badly broken zone from 18 to 28 feet. Joints in this zone are open. Joint originating in broken zone at 26 feet strikes northeast and apparently is the same as the joint that intersects tangent joint on northwest wall at this depth. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-V - Continued

| Depth (feet) | |
|---|---|
| 38 | Tangential joint now single trace near north wall striking southeast. Joint that originates in broken zone at 26 feet dips steeply southeast, and trace on wall of hole is drifting eastward. |
| 50 | Roots in joints on west wall. |
| 57 | Northeast striking joint has roots at 57 feet. Bottom of hole strongly jointed. Hole belled to 6 feet 8 inches from 50 to 58 feet. |

General note: Hole is in moderately jointed rock. Tuff penetrated is fairly dense and not strongly jointed except 50 to 58 feet.

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-W Diameter - 6 feet; depth - 58 feet

| Depth (feet) | |
|---|---|
| 0-3.6 | Soil, brown. |
| 4 | Master Joint on west side of hole is 1 inch clay filled. |
| 12 | Master joint dips to north and is clay and root filled up to 1 inch. Tuff is light gray and dense. Small joints are clay filled. |
| 19 | Master joint is 2.9 feet west of north and is clay filled 1/8 inch. Two joints dip 45° north at 18 feet. Joint on southwest wall, 2.5 feet from master joint, is clay filled $\frac{1}{4}$ inch. |
| 26 | Northeast striking joint is tangent to hole on south wall. It causes pluck out from 26 feet to bottom. |
| 30 | Two joints dip 45° into master joint 2.7 feet west of north. |
| 37 | Roots in plucked zone in south edge of hole. |
| 44 | Master joint 2.2 feet west of north is open locally up to $\frac{1}{4}$ inch. |
| 51-58 | Roots in pluck zone on south wall. Joints appear to strike northeast. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-X Diameter - 6 feet; depth - 56 feet

| Depth (feet) | |
|---|---|
| 0-2.5 | Soil zone, brown clay, slightly pumiceous with large roots throughout. Soil thickens slightly on west wall and grades into pumice zone on east wall. |
| 2.5-4 | Pumice with brown clay and roots. |
| 4-5.5 | Weathered zone with tuff and some pumice in a matrix of brown clay. One system of vertical joints occurs below the weathered zone on the northeast wall. A few flat-lying joints found on southwest wall are about 1/8 inch clay filled. |
| 10 | Major vertical joint strikes north-northeast and is 1/8 inch clay filled. One joint dips steeply east. |
| 20 | Major joint on northeast wall dips to the northwest at a low angle. A few irregular minor joints, which dip to the east and south, are found on the north wall. Irregular minor joints found on the south wall are flat-lying. |
| 30-41 | Hole is badly broken between major joints on west wall, southward around hole to major joint on northeast wall. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 2 - Continued

Hole 2-X - Continued

| Depth (feet) | |
|---|---|
| 45 | Major joints on north-northeast and southwest walls strike southwest and apparently are same system. Intersection on southwest wall open up to 3/4 inch locally, but intersections on northeast wall are open 1/8 inch. South and east walls ~~is~~ are badly broken between these major joints. Vertical joints are found on the north wall from 42 feet to the bottom of hole. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 3

Hole 3-C Diameter - 6 feet; depth - 87 feet

| Depth (feet) | |
|---|---|
| 0-3 | Soil and fill. |
| 3 | Joint striking south-southwest dips north and is $\frac{1}{4}$ inch clay filled. |
| 7 | System of flat-lying joints. |
| 15 | System of joints striking north-northeast dip about 20° west. Joint mentioned at 3 feet now vertical and open 1/16 inch. |
| 21 | Joint mentioned at 3 feet now dipping about 80° south. |
| 28-30 | Brecciated zone, system of joints striking east-northeast dipping from 10° to 20° north. |
| 33 | Joint mentioned at 3 feet now vertical, strike to north at 28 feet. South wall shows joint that strikes northeast. Pluck along joint which is open up to $\frac{1}{2}$ inch. |
| 33-45 | Joint in southeast wall that is clay filled $\frac{1}{2}$ inch. At 45 feet joint mentioned at 3 feet is here closed. |
| 53 | Southeast wall is badly broken. Northwest wall contains vertical joint striking west-northwest and is 1/8 inch clay filled. |
| 58 | Joint mentioned at 53 feet terminates against apex of northeast striking joint which is tangent to hole on northwest wall. Clay filling up to $\frac{1}{4}$ inch thick. Several plucks along each fracture. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 3 - Continued

Hole 3-C - Continued

| Depth (feet) | |
|---|---|
| 63 | Southwest limb of joint that showed apex at 58 feet is here a hair line. Northeast joint plucked out, has clay filling. Joint on southeast wall strikes east, dips 85° south, and is open ½ inch. West wall contains north striking vertical joint that is clay lined and is open 1/8 inch. North wall contains vertical, north striking joint. |
| 72 | Joint on southeast wall terminates. |
| 78 | Water-laid sand on north wall is 2.5 feet thick. Two joints below sand are 2 and 6 inches wide and extend to bottom of hole at 87 feet. Sand is 0.85 feet thick on west wall, 0.5 feet thick on east wall, and 0.4 feet thick on south wall. |
| 78-87 | Joints beneath sand strike northeast and are closed. Joints on north wall are filled with sand and range from 2 inches to over 1 foot wide. Some pieces of tuff are found in the sand filling. Tunnel drift to the north is about 2 feet in diameter. It intersects two northeast-striking, sand-filled joints about 2 inches wide, 2 feet apart, approximately 8 feet from the wall of the large-diameter hole. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 3 - Continued

Hole 3-C - Continued

Note: Hole 3-C was re-examined after shot in hole 3-A. As the working caisson was set, only the bottom 8 feet of hole was re-examined. The sand-filled joints on the north wall were open as much as 1 foot from the hole face where the sand was shaken out by the concussion of the shot. Partial collapse of the 24-inch drift occurred about 8 feet from the hole between the two northeast-striking joints. The drift was partly filled with rubble at this point.

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 4

Hole 4-K Diameter - 6 feet; Depth - 58 feet

| Depth (feet) | |
|---|---|
| | Soil and weathered zone are covered with casing. |
| 8 | Southwest wall shows apex of joint, which is clay and root filled up to 1 inch, and strikes west-northwest, dips 70° northeast. East wall has joint which strikes north-northeast with apex upward at 10 feet. Joint is 2 inches clay filled. Northwest wall shows vertical joint striking northwest, clay filled up to 6 inches near top and 2 inches at 9 feet. |
| 15 | Joint on southwest wall is clay and root filled. Joint on northwest wall is here clay and root filled about 1 inch. Tuff has devitrified pumice fragments up to 1 inch in length. |
| 18 | Pluck out at joint on southwest wall. Joint on northwest wall splits. Northernmost joint strikes northwest, is clay filled ½ inch, and terminates at 40 feet. Westernmost joint dies out at 22 feet. |
| 26 | Dip of the joint on southwest wall at 8 feet is now 80°, northeast several marked plucks from this joint, which is clay and root filled 1 inch. |
| 33 | Joint described at 26 feet is here trending vertical reverses in dip farther down. It is now striking west-northwest and dipping 80° south-southeast. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 4 - Continued

Hole 4-K - Continued

| | |
|---|---|
| 37 | Tuff is less strongly jointed below this depth. |
| 42 | On the northeast wall is a system of vertical north-northwest striking joints that are clay filled. |
| 58 | Joint mentioned on southwest wall at 8, 26, and 33 feet is now vertical and strikes northeast. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 4 - Continued

Hole 4-M Diameter - 6 feet

| Depth (feet) | |
|---|---|
| 0-5 | Soil entirely stripped off. East wall shows large vertical joint that strikes northwest and is 1 inch clay filled. North wall has 3/4-inch clay-filled joint that strikes northwest. Southwest wall has 2 vertical joints that are one foot apart and are 1 inch clay filled. South wall has vertical fracture striking north which is $1\frac{1}{2}$ inch clay filled. |
| 10 | Brecciated zone on northeast wall. |
| 15 | Joint system on north-northeast wall contains joints that are open up to $\frac{1}{2}$ inch. |
| 20 | Flat-lying joints all around hole. Joint on north wall now $\frac{1}{4}$ inch clay filled. |
| 25 | Vertical joints mentioned from 0 to 5 feet still persist. Flat-lying joints at 24 and 28 feet. |
| 30 | Joint on south wall is now open $\frac{1}{4}$ inch. |
| 35 | Pluck out along joints. on southwest wall. |
| 40 | Joint splits at 33 feet on south wall, dips eastward at 45°, and both branches are open up to 1/16 inch. |
| 50 | Vertical joints still persist and are $\frac{1}{2}$ to 1 inch clay filled. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 4 - Continued

Hole 4-0 Diameter - 7 feet; Depth - 58 feet

| Depth (feet) | |
|---|---|
| 0-2 | Soil and weathered zone. |
| 2-26 | Northwest and southeast wall of hole has vertical joints that are 1 inch clay filled and strike northwest. On southeast wall a joint strikes north, is near vertical, and contains clay filling up to 3 inches. Hole walls appear to be tight except for the above-mentioned joints. |
| 26-32 | Northeast wall of hole contains apex of joint. West limb dips at 45° to 30 feet and intersects vertical northwest striking joint on northwest wall. East limb of joint is vertical and 1 to 3 inches clay filled. |
| 32 | Northeast wall is brecciated. |
| 35 | Hole reduced in diameter about 4 to 6 inches. |
| 41 | Northwest striking joint is 1 to 3 inches clay filled and contains a few roots. |
| 48 | Southwest wall has northwest striking joint that shows apex with limbs downward. Limbs are clay filled up to 1 inch. Joints noted at 41 feet here are dipping (45° or less) and are clay filled. On southeast wall joint strikes northwest, persists to bottom of hole, and is 1 inch clay filled. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 4 - Continued

Hole 4-Y Diameter - 6 feet; Depth - 69 feet

| Depth (feet) | |
|---|---|
| 0-2 | Soil zone is thin on weathered tuff zone. |
| 7 | Southeast wall has joint that is clay filled and strikes northwest, dips 80° northeast. |
| 22 | South wall has north-northwest striking joint which dips west at 85°. |
| 28 | Pluck out from above joint, which appears to be $\frac{1}{4}$ inch clay filled. Joint mentioned at 7 feet is here open 1/16 inch. |
| 29 | Northwest wall shows apex upward of joint. This joint strikes east-northeast and dips 80° to the northwest. Also on the northwest wall is a vertical joint that strikes south-southeast. |
| 32-45 | Southeast wall of hole is badly broken along upward apex at joint. |
| 46 | Hole badly broken on southwest wall. Master joint is vertical and strikes east-southeast. It is open $\frac{1}{2}$ inch. |
| 51 | Very few joints except master joint mentioned at 46 feet. |
| 57 | Southeast wall contains a system of high angle joints. |
| 62 | Water-laid sand, $1\frac{1}{2}$ feet thick on north wall and very thin or stripped away on the other walls of the hole. |

Table 26.--Reconnaissance notes for large-diameter holes - Continued

Area 4 - Continued

Hole 4-Y - Continued

| Depth (feet) | |
|---|---|
| 62-69 | Wall of hole contains very friable tuff below sand. West wall contains joint striking north-northeast, dipping 85° north. West wall has joint which is vertical and strikes north-northeast. These two joints apparently are not the same. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 10

Area 10 contains two 6-foot diameter holes 25 feet apart and drilled to a depth of about 60 feet. The two holes are connected at the bottom by a horizontal drift. Only the westernmost hole and the drift were examined.

West hole

Diameter - 6 feet
(except for bottom 12 feet, which is 13 feet)

| Depth (feet) | |
|---|---|
| 0-1 | Back-fill, broken tuff. Most of soil is stripped off. |
| 1-3.5 | Pumice, layered, light gray with brownish clay lenses included. |
| 3.5-5 | Weathered zone containing partially weathered tuff fragments in a matrix of brown clay. |
| 5 | Joint on south wall is $\frac{1}{4}$ inch clay filled and strikes north-northeast. Tuff has pebble-size, purplish devitrified pumice fragments. |
| 10 | Broken zone. |
| 17 | Joint mentioned at 5 feet persists through broken zone, but is only 1/8 inch clay filled. Joint on east-northeast wall originates in broken zone, strikes northeast, and is $\frac{1}{4}$ inch clay filled. |
| 18-23 | Badly broken zone. Joints are irregular; roots noted in north striking joint on northeast wall. |

Table 25.--Reconnaissance notes for large-diameter holes - Continued

Area 10 - Continued

West hole - Continued

| Depth (feet) | |
|---|---|
| 33 | Joints strike northwest and north and are open 1/8 to $1\frac{1}{2}$ inches. |
| 48 | Top of 13-foot diameter hole. Joint striking south-southwest. Joints on north-northeast wall are $\frac{1}{4}$ inch clay filled. |
| 50 | Top of weathered zone in tuff above sand dips to the northeast. |
| 54 | Top of sand dips to the northwest at a low angle. Sand is stripped away on southwest wall and thickens to about 2 feet on east wall near drift. Joints found about 2 feet below sand are sand filled and open from $\frac{1}{4}$ to 2 inches. Tuff below sand is weathered, highly pumiceous, and friable. Joint in bottom of west hole is open several feet below bottom of hole. |

Area 10

The drift extends east-west between the two large diameter vertical holes. On entering the drift from the east hole, weathered pumiceous tuff extends upward on the north wall and then cuts across the top of the drift to the south wall a few feet east of the portal to west hole. The tuff is about 9 feet thick on the north side of the drift and contains an abundance of quartz and irregular brownish iron-stained streaks.

Figure 21.--Graph of moisture content and lithology in test hole 1M-2, TA-49, Los Alamos County, N. Mex.

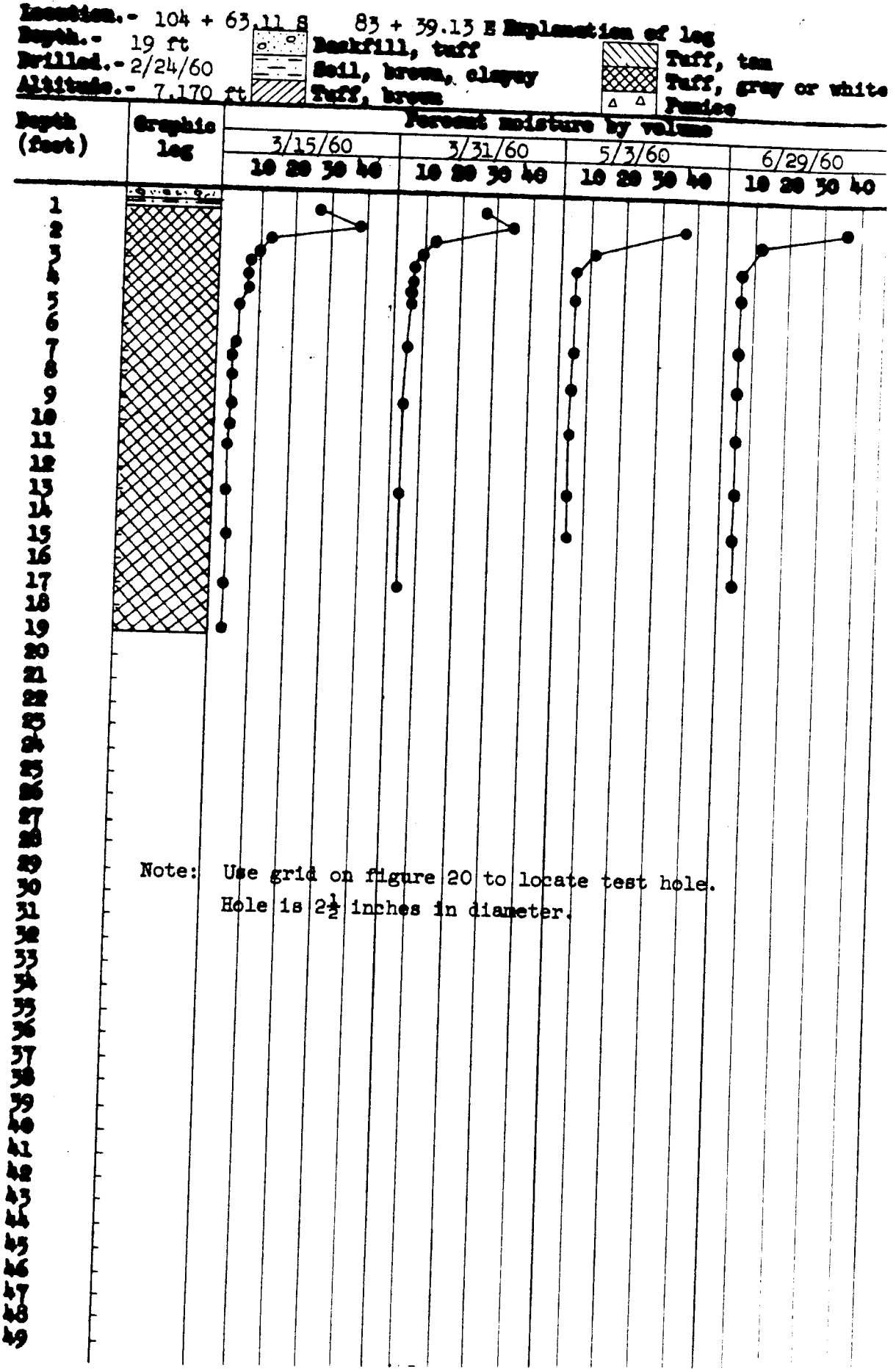


Figure 22.--Graph of moisture content and lithology in test hole 2M-1, TA--, Los Alamos County, N. Mex.

**Location.-** 104 + 72.67 S 99 + 28.26 E
**Depth.-** 49 ft
**Drilled.-** 2/17/60
**Altitude.-** 7,129 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice

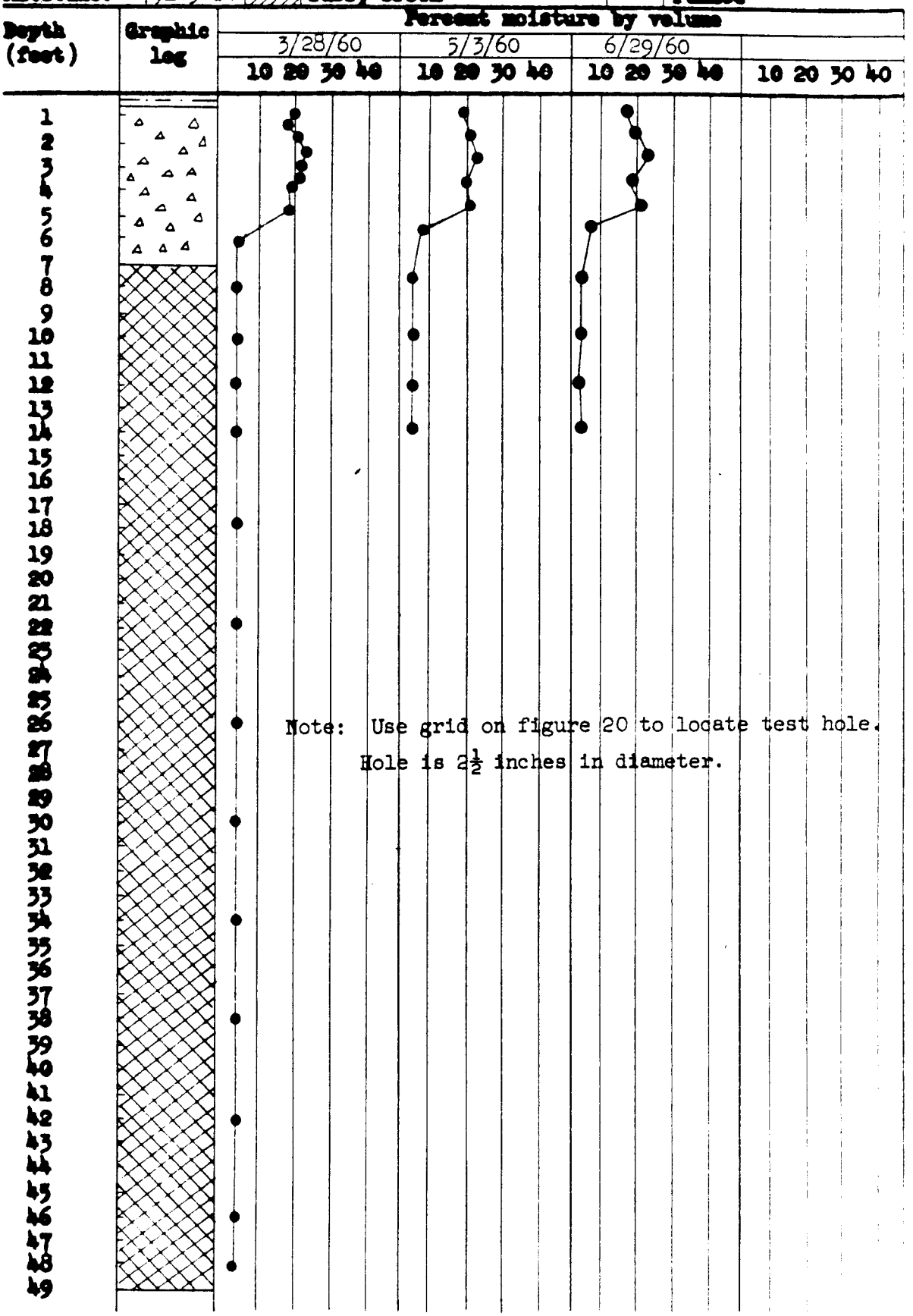
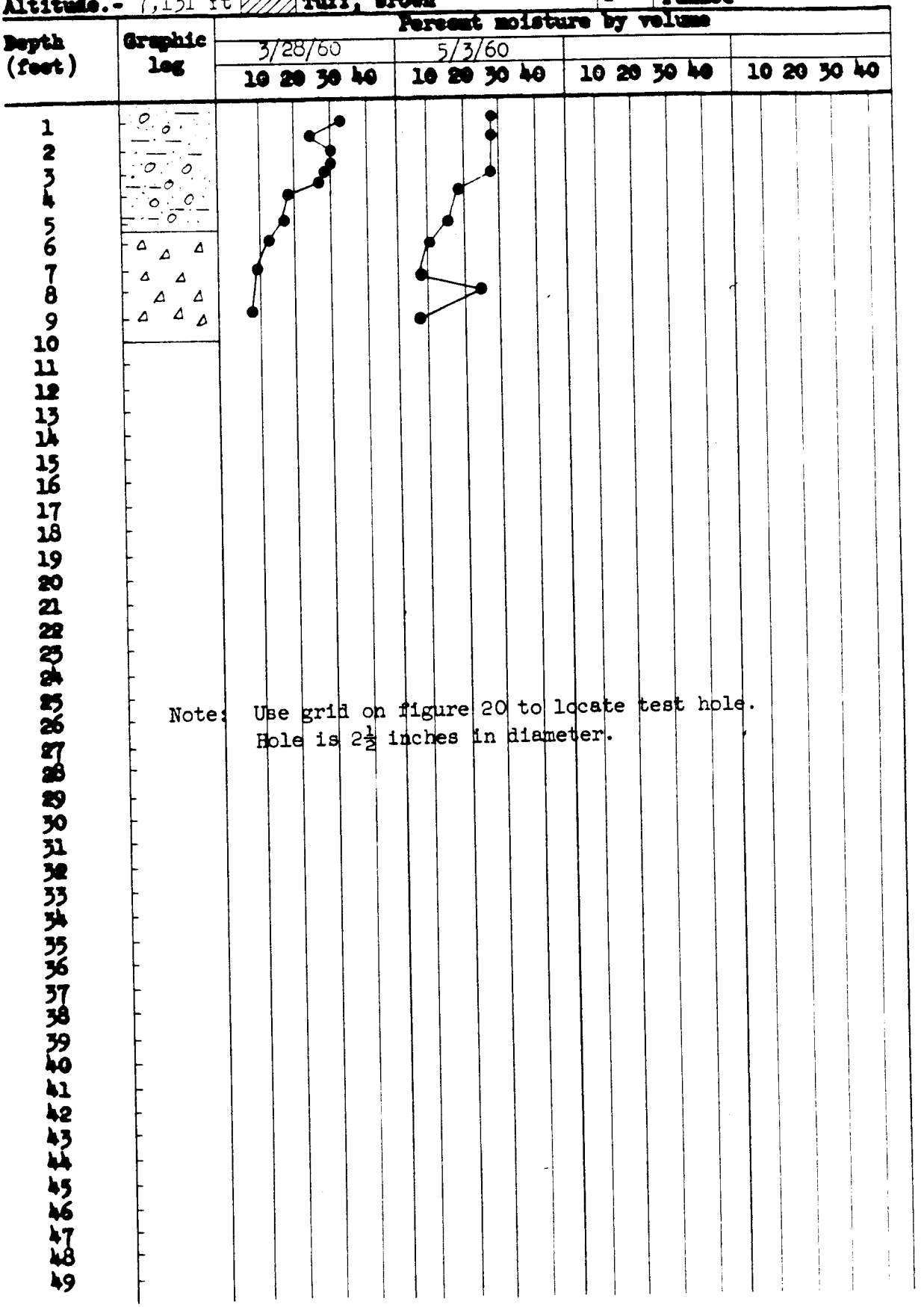


Figure 23.--Graph of moisture content and lithology in test hole 2M-2, TA-49, Los Alamos County, N. Mex.

**Location.-** 107 + 11.61 S 100 + 04.79 E
**Depth.-** 10 ft
**Drilled.-** 2/17/60
**Altitude.-** 7,131 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice




Note: Use grid on figure 20 to locate test hole.
Hole is 2½ inches in diameter.

Figure 24.--Graph of moisture content and lithology in test hole 3M-1, TA-49, Los Alamos County, N. Mex.

**Location.-** 115 + 97.11 S 82 + 03.29 E
**Depth.-** 50 ft
**Drilled.-** 2/15/60
**Altitude.-** 7,163 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice

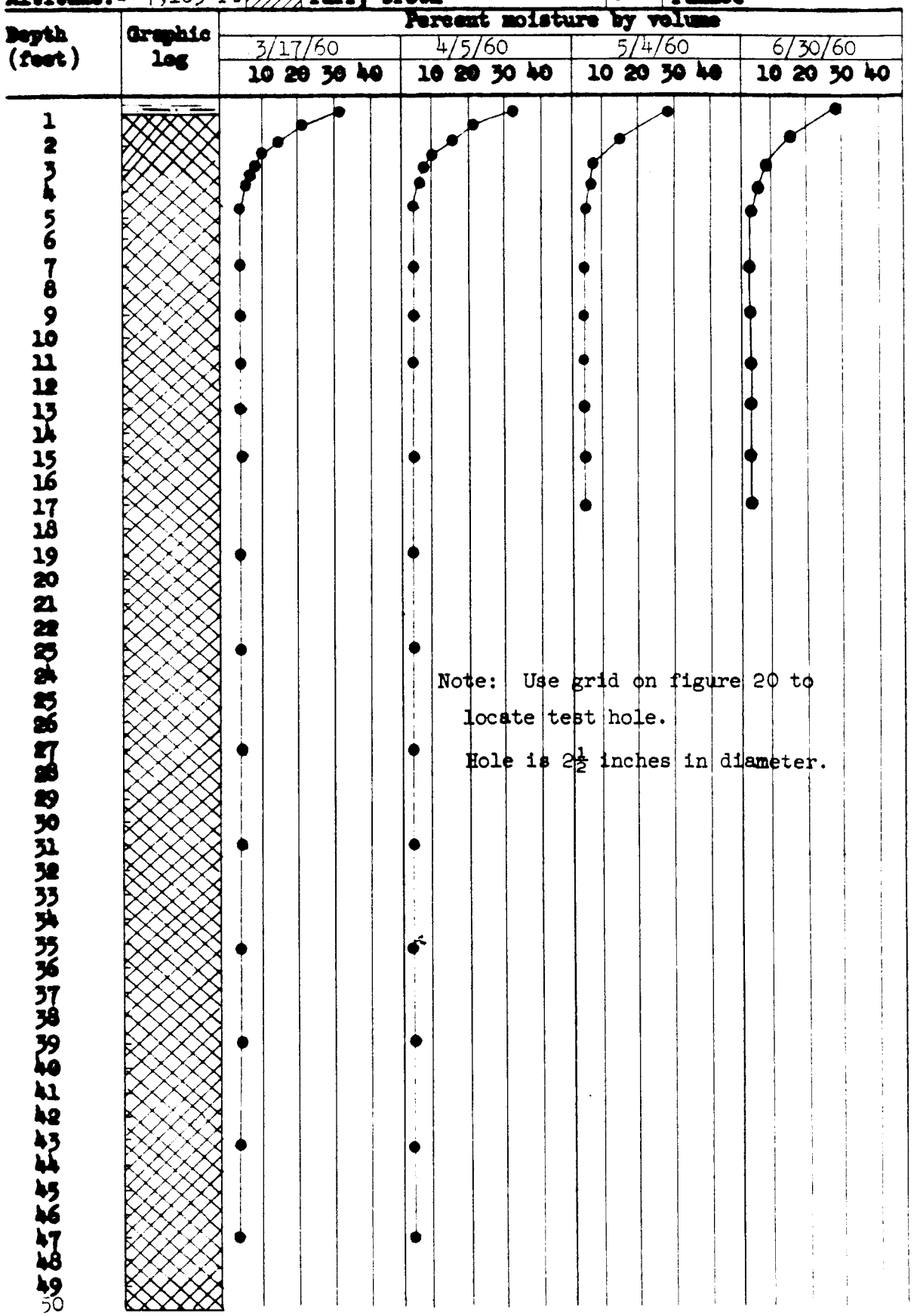


Figure 25.--Graph of moisture content and lithology in test hole 3M-2, TA-49, Los Alamos County, N. Mex.

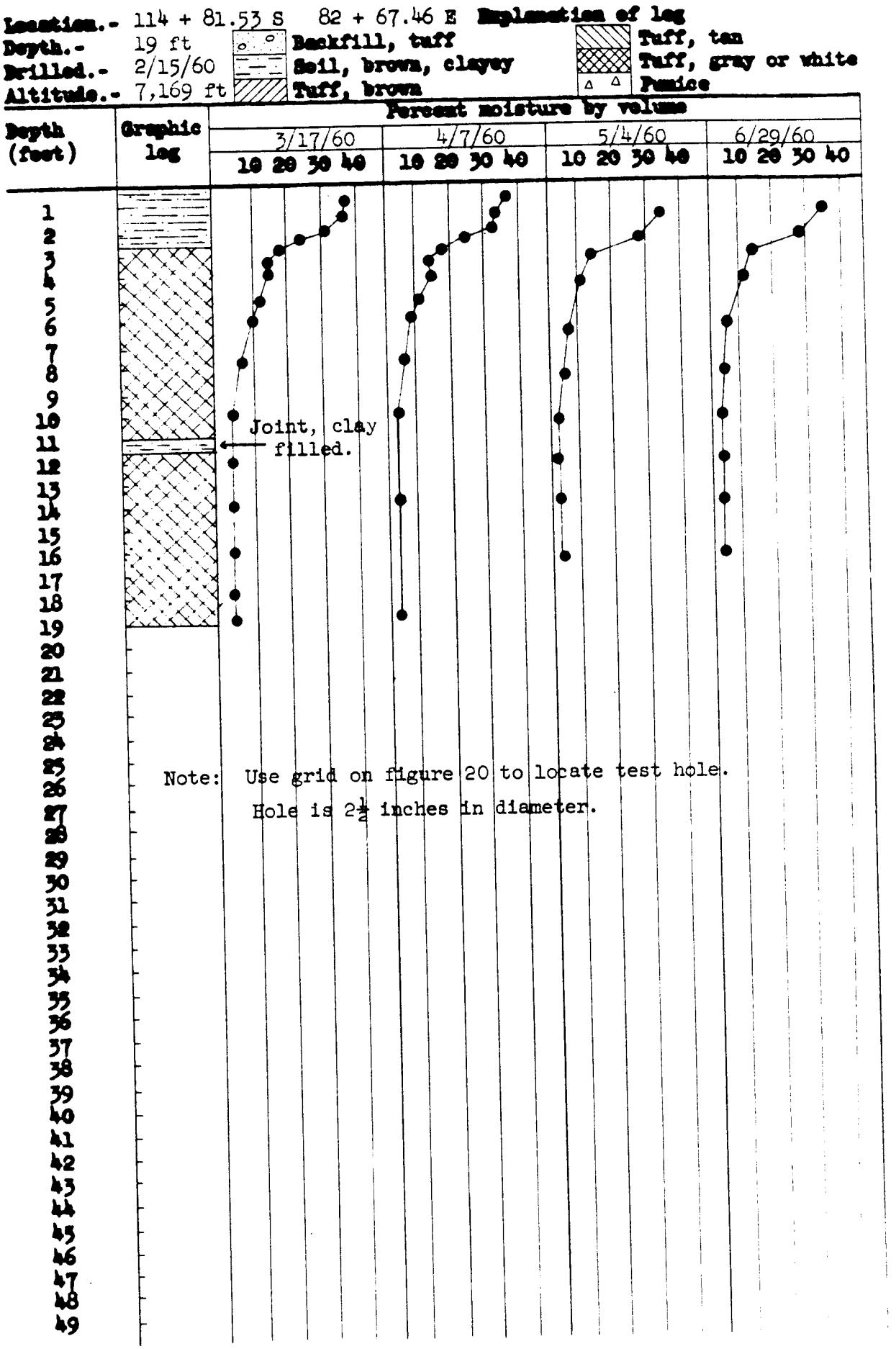
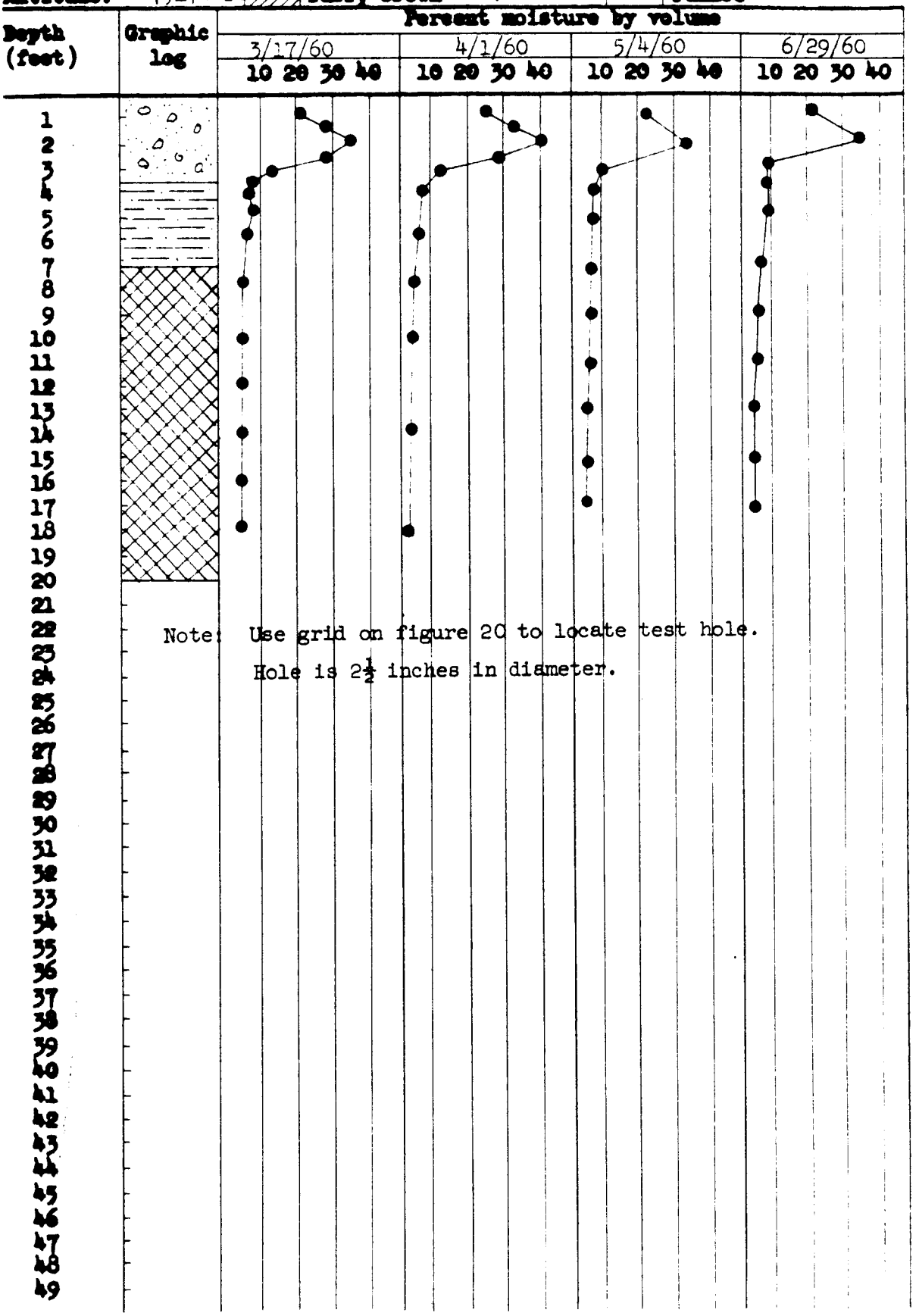


Figure 26.--Graph of moisture content and lithology in test hole 3M-3, TA-49, Los Alamos County, N. Mex.

**Location.-** 114 + 56.29 S 79 + 95.70 E
**Depth.-** 20 ft
**Drilled.-** 2/15/60
**Altitude.-** 7,174 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice



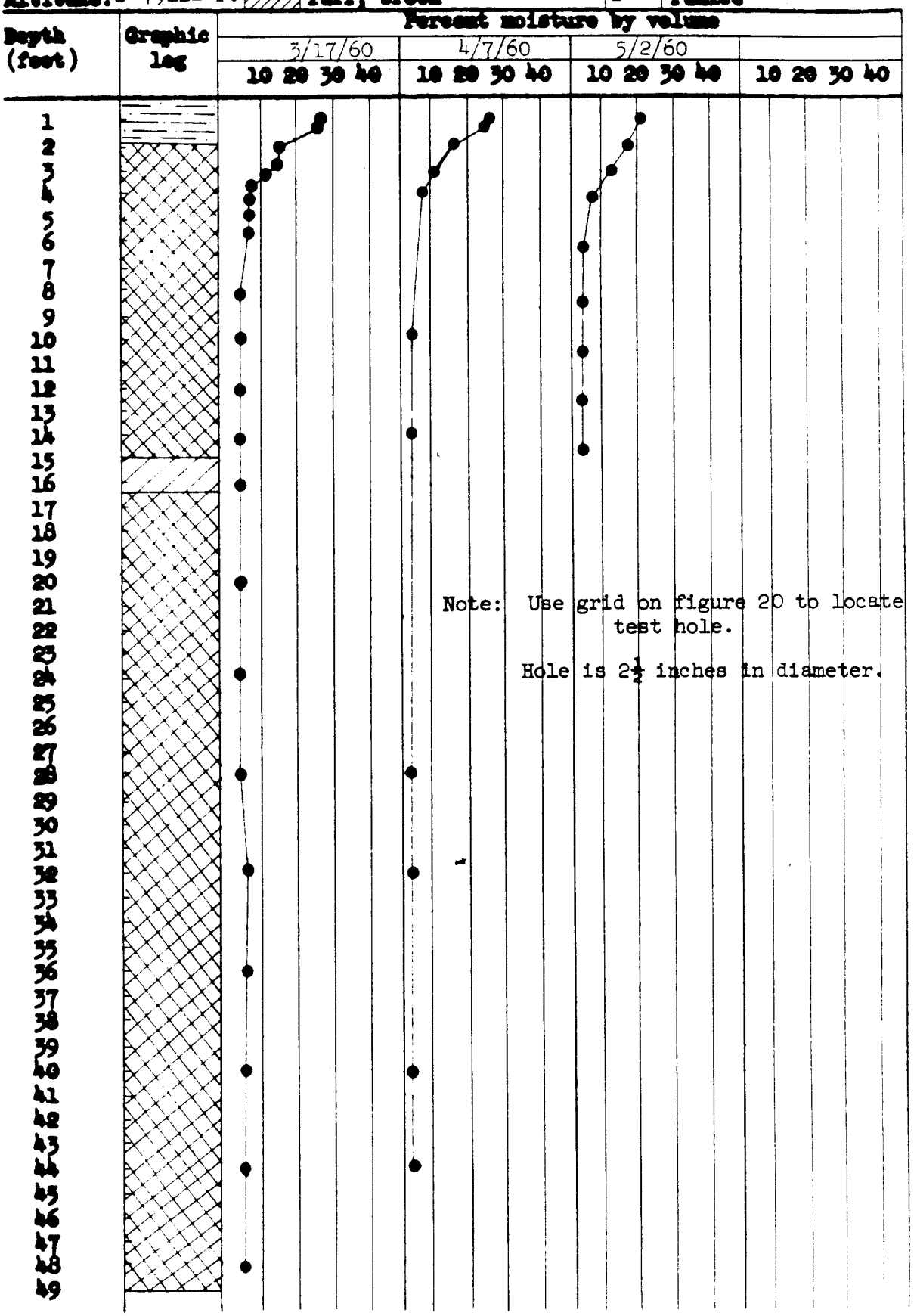

Note: Use grid on figure 20 to locate test hole.
Hole is 2½ inches in diameter.

Figure 27.--Graph of moisture content and lithology in test hole 4M-1, TA-49, Los Alamos County, N. Mex.

**Location.-** 121 + 29.23 S 96 + 43.59 E
**Depth.-** 49 ft
**Drilled.-** 2/16/60
**Altitude.-** 7,112 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, grey or white
- Pumice




Note: Use grid on figure 20 to locate test hole.

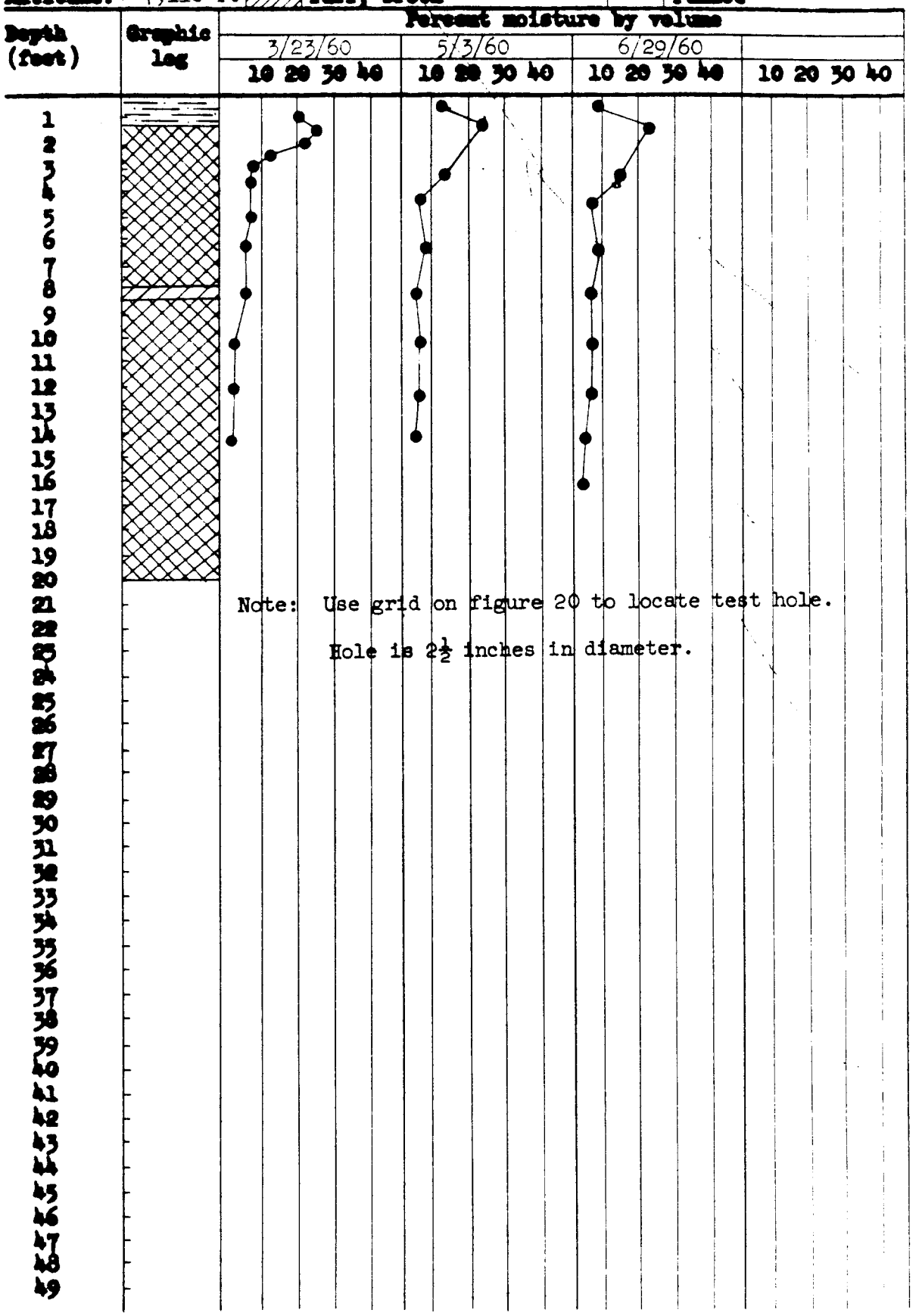
Hole is 2½ inches in diameter.

Figure 28.--Graph of moisture content and lithology in test hole 4M-2, TA-49, Los Alamos County, N. Mex.

**Location.-** 120 + 56.96 S 94 + 70.47 E
**Depth.-** 20 ft
**Drilled.-** 2/15/60
**Altitude.-** 7,116 ft

**Explanation of log**

- **Backfill, tuff**
- **Soil, brown, clayey**
- **Tuff, brown**
- **Tuff, tan**
- **Tuff, gray or white**
- **Pumice**




Note: Use grid on figure 20 to locate test hole.

Hole is 2½ inches in diameter.

Figure 29.--Graph of moisture content and lithology in test hole 4M-3, TA-49, Los Alamos County, N. Mex.

**Location.-** 122 + 76.04 S 96 + 93.84 E
**Depth.-** 19 ft
**Drilled.-** 2/15/60
**Altitude.-** 7,107 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice

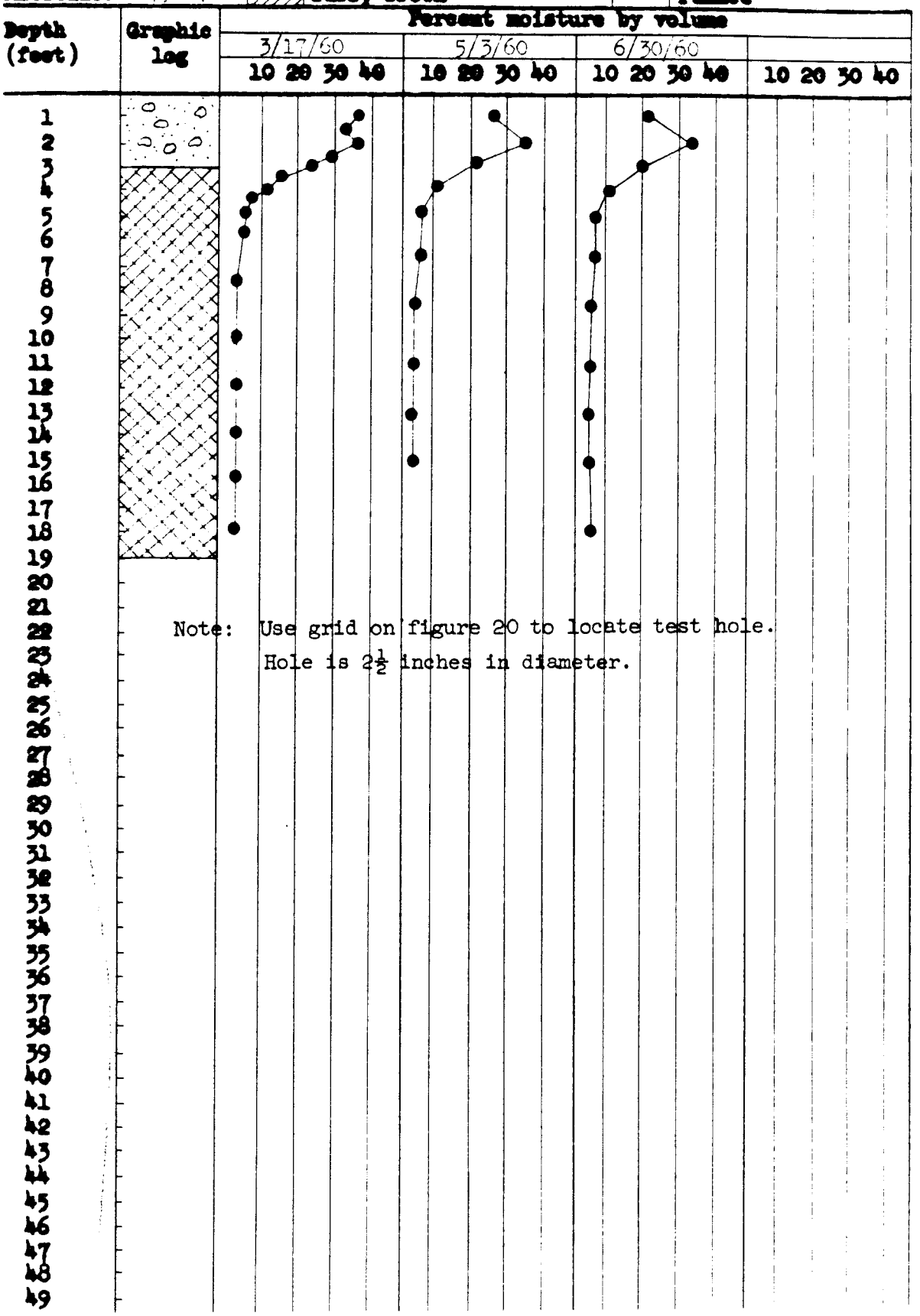


Figure 50.--Graph of moisture content and lithology in test hole 4M-4, TA-49, Los Alamos County, N. Mex.

**Location.-** 118 + 71.52 S 94 + 93.95 E
**Depth.-** 19 ft
**Drilled.-** 2/16/60
**Altitude.-** 7,122 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice

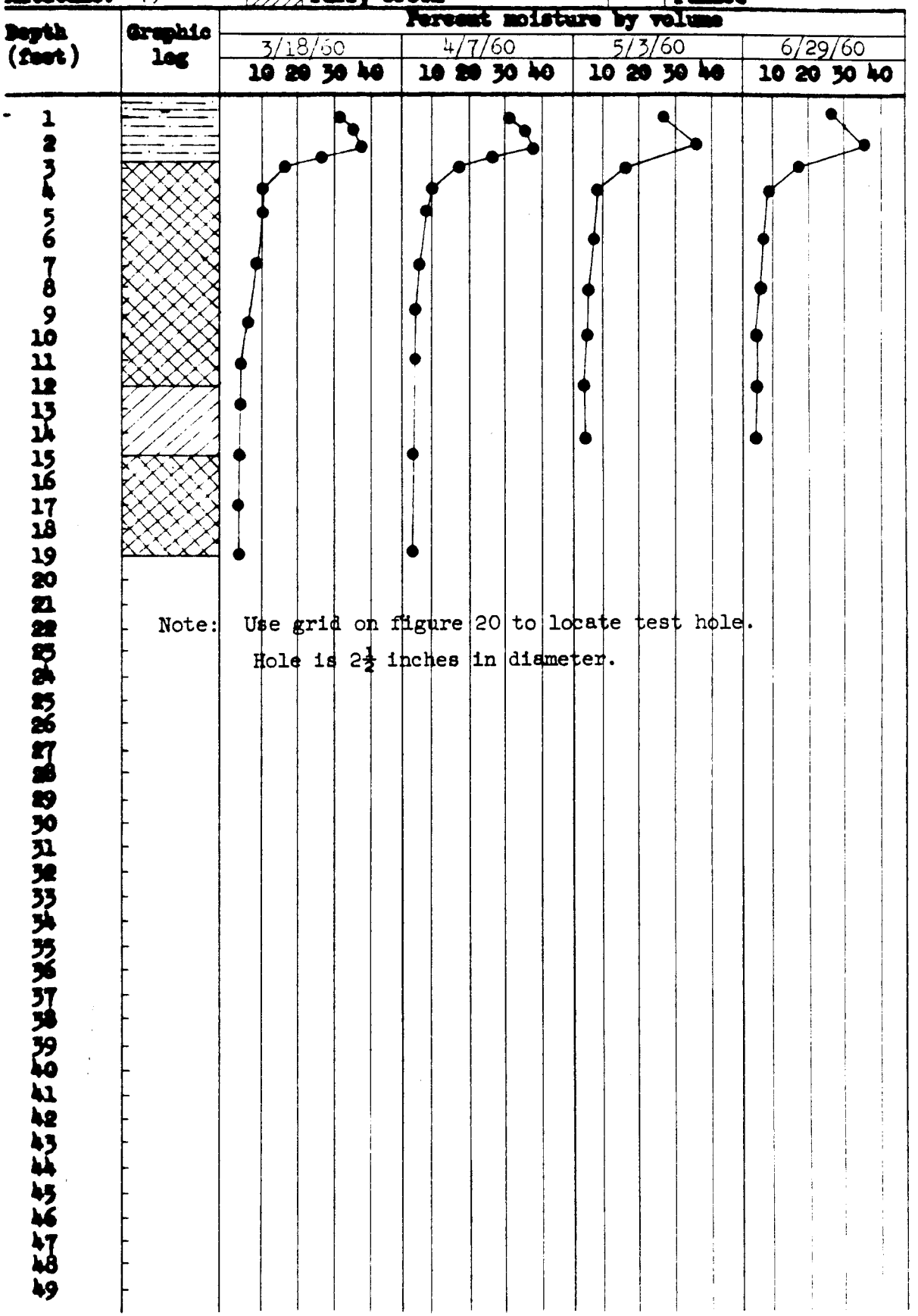


Figure 51.--Graph of moisture content and lithology in test hole 5M-2, TA-49, Los Alamos County, N. Mex.

**Location.-** 111 + 04.87 S 92 + 37.59 E
**Depth.-** 19 ft
**Drilled.-** 2/16/60
**Altitude.-** 7,146 ft

**Explanation of log**

- **Backfill, tuff**
- **Soil, brown, clayey**
- **Tuff, brown**
- **Tuff, tan**
- **Tuff, gray or white**
- **Pumice**

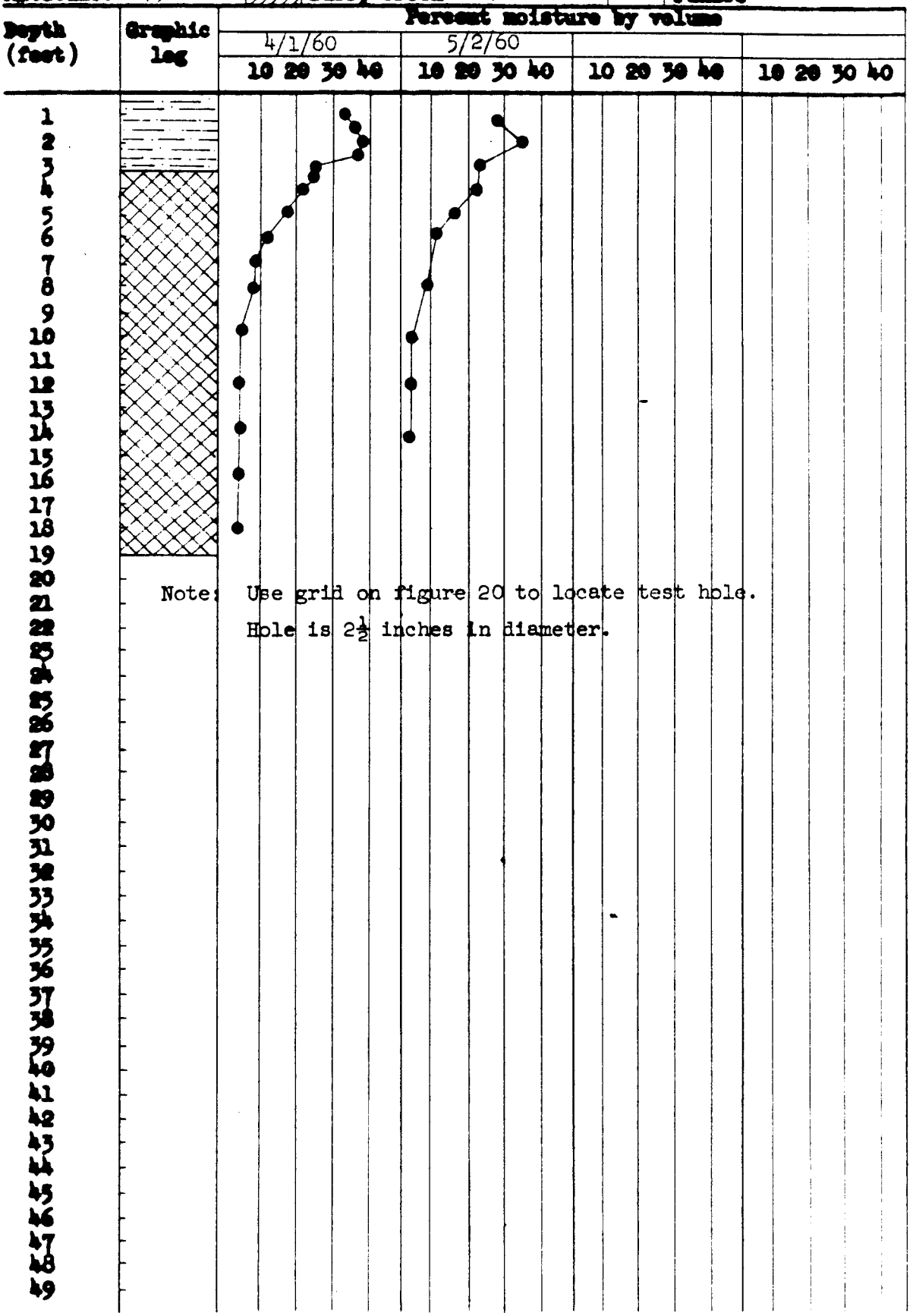


Figure 32.--Graph of moisture content and lithology in test hole 9M-4, TA-49, Los Alamos County, N. Mex.

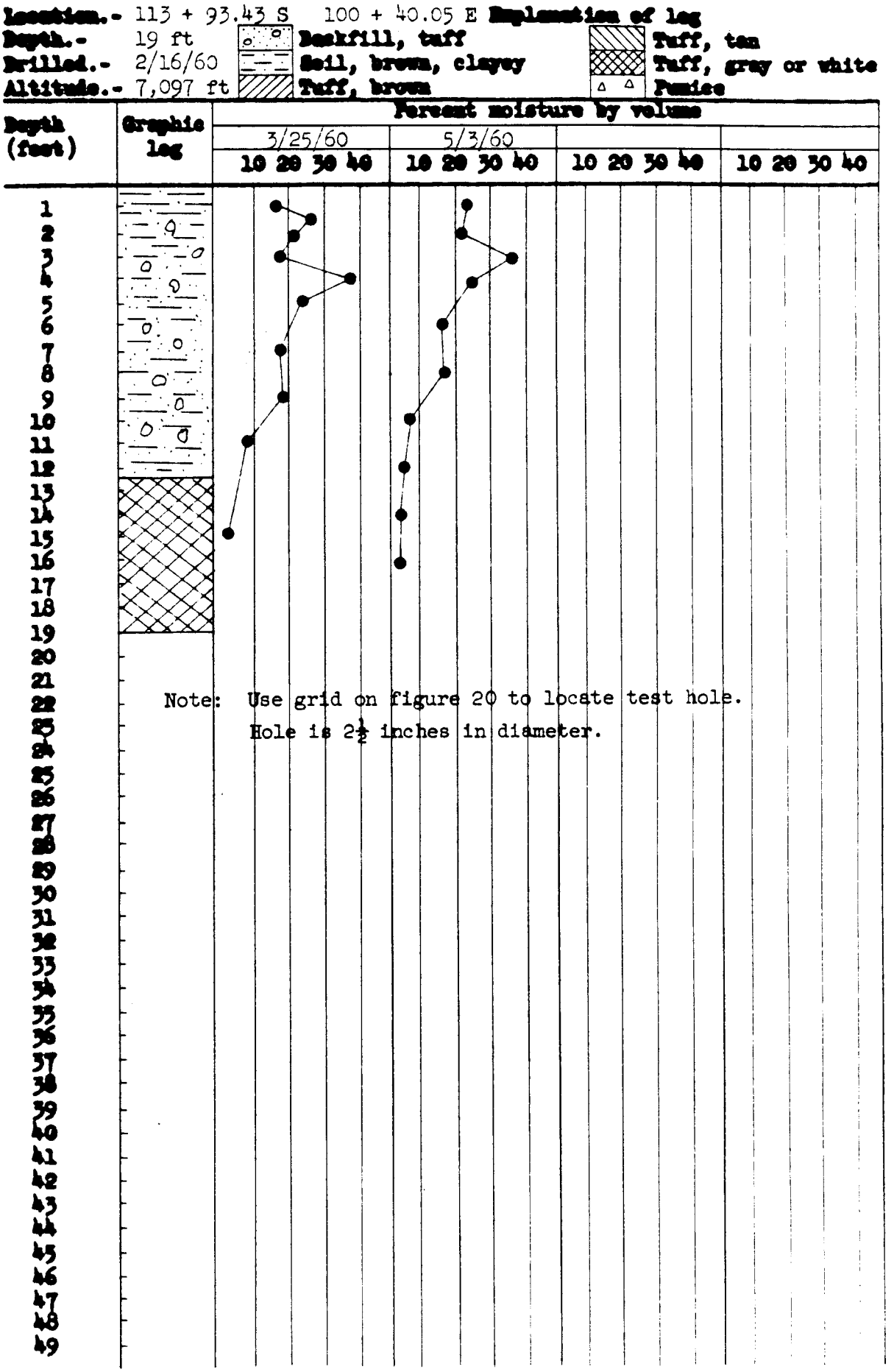
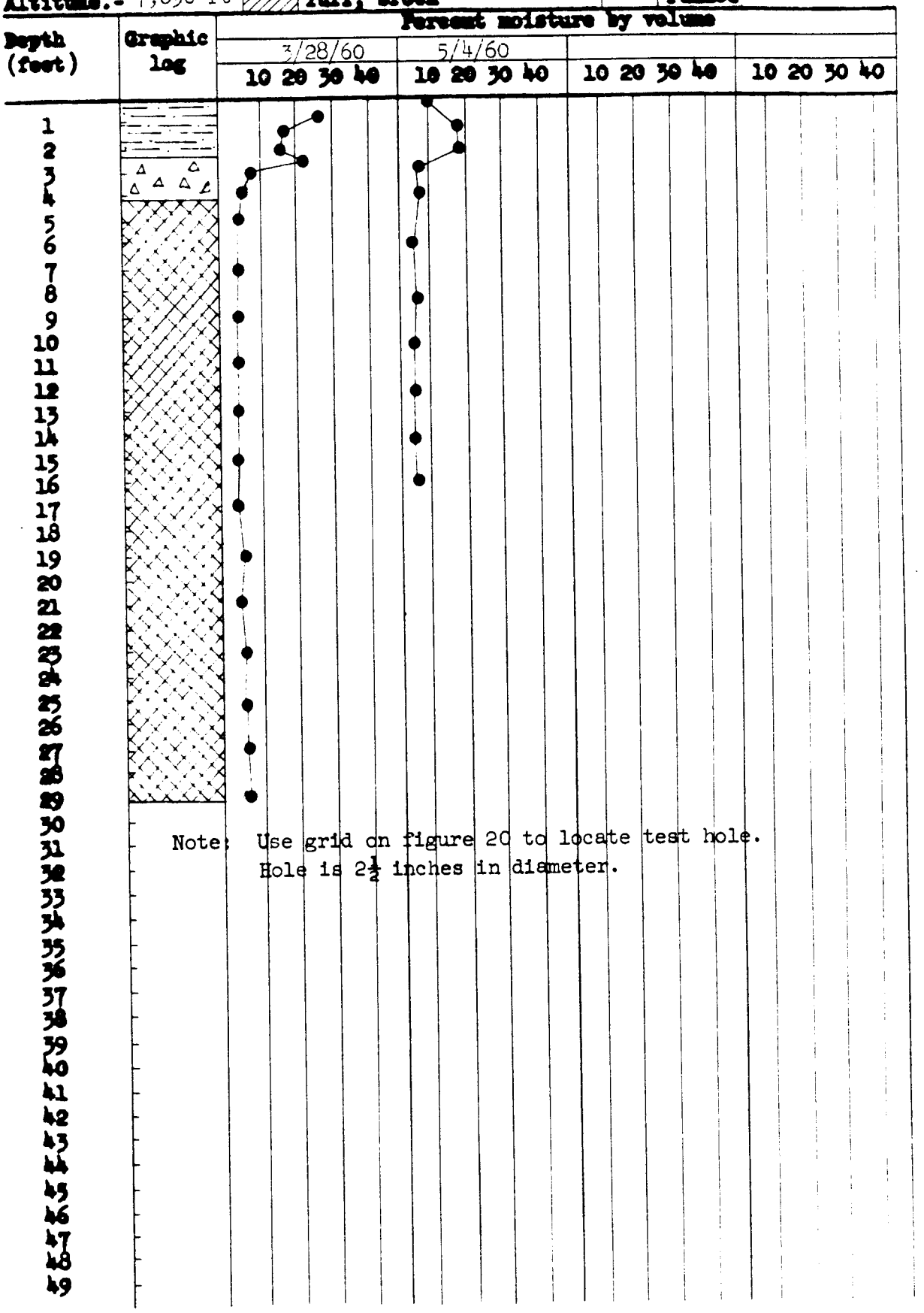


Figure 33.--Graph of moisture content and lithology in test hole 10M-1. TA-49, Los Alamos County, N. Mex.

**Location.-** 104 + 95.62 S 110 + 30.66 E
**Depth.-** 29 ft
**Drilled.-** 2/23/60
**Altitude.-** 7,090 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice



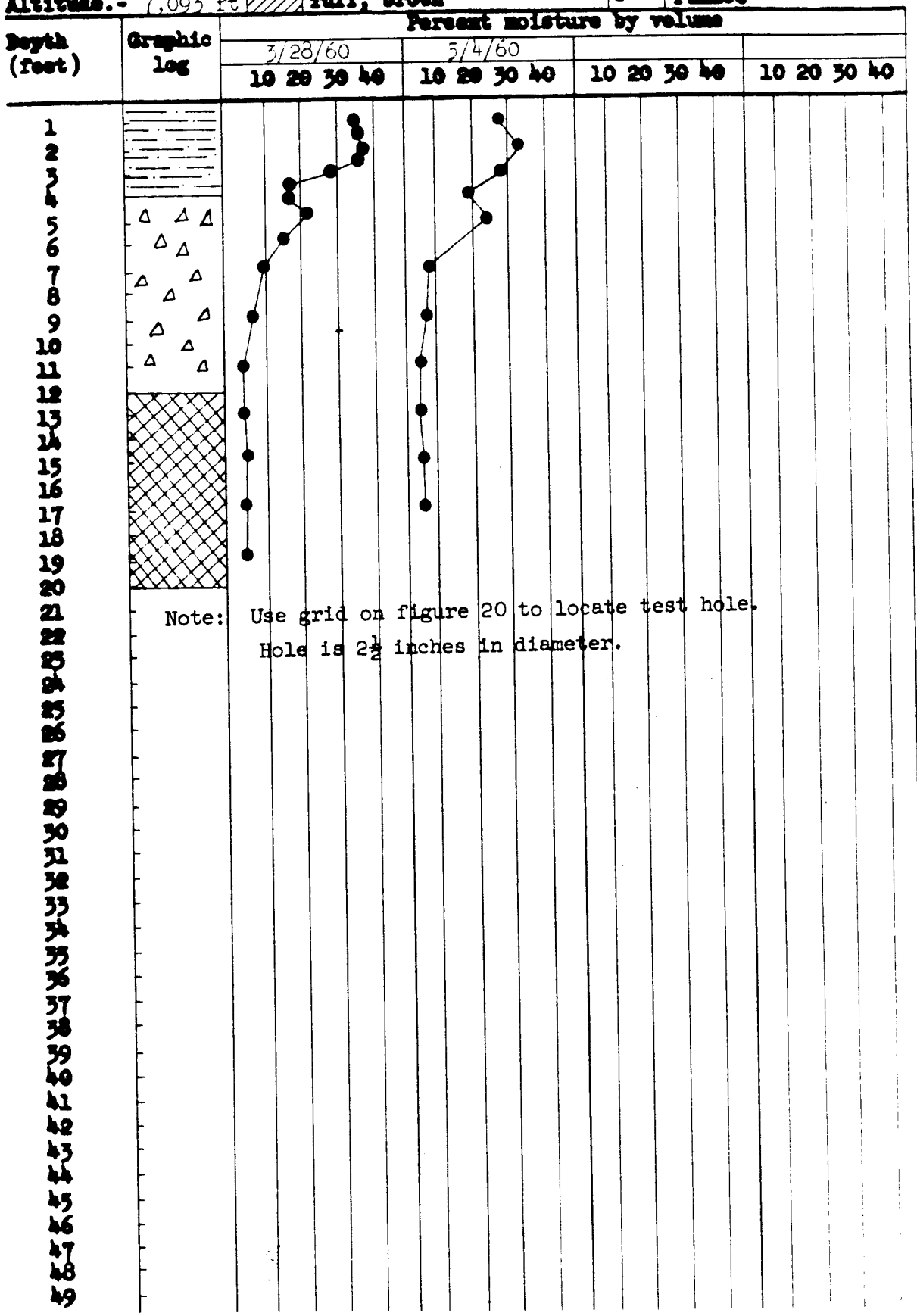

Note: Use grid on figure 20 to locate test hole.
Hole is 2½ inches in diameter.

Figure 34.--Graph of moisture content and lithology in test hole 10M-2, TA-49. Los Alamos County, N. Mex.

**Location.-** 104 + 53.61 S 108 + 68.66 E
**Depth.-** 20 ft
**Drilled.-** 2/23/60
**Altitude.-** 7,093 ft

**Explanation of log**

- **Backfill, tuff**
- **Soil, brown, clayey**
- **Tuff, brown**
- **Tuff, tan**
- **Tuff, gray or white**
- **Pumice**




Note: Use grid on figure 20 to locate test hole.
Hole is 2½ inches in diameter.

Figure 35.--Graph of moisture content and lithology in test hole 1M-1, TA-49, Los Alamos County, N. Mex.

**Location.**- 104 + 40.33 S 85 + 48.24 E
**Depth.**- 49 feet
**Drilled.**- 2/27/60
**Altitude.**- 7,162 ft

**Explanation of log**
- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice

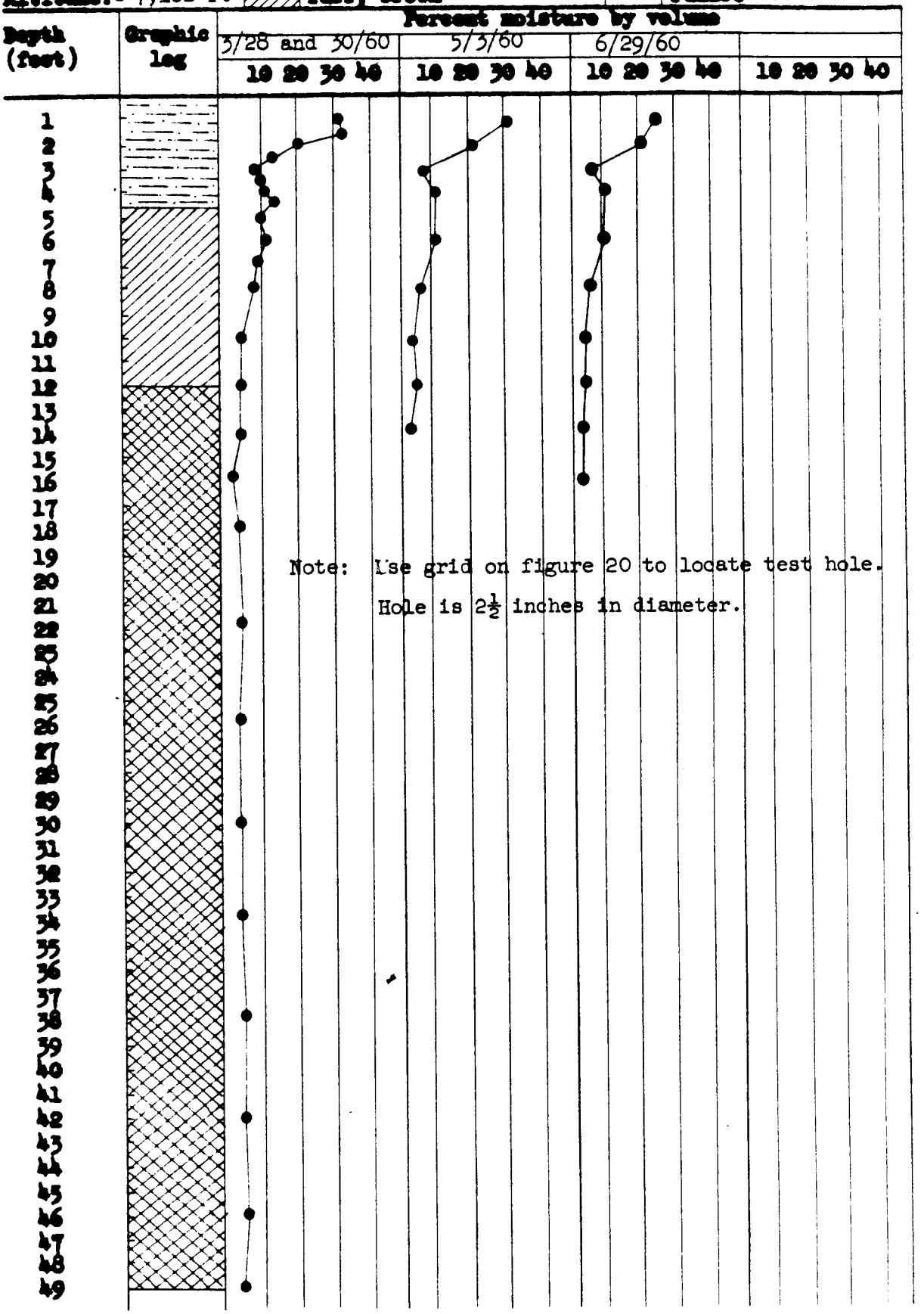


Figure 36.--Graph of moisture content and lithology in test hole 1M-3, TA-49, Los Alamos County, N. Mex.

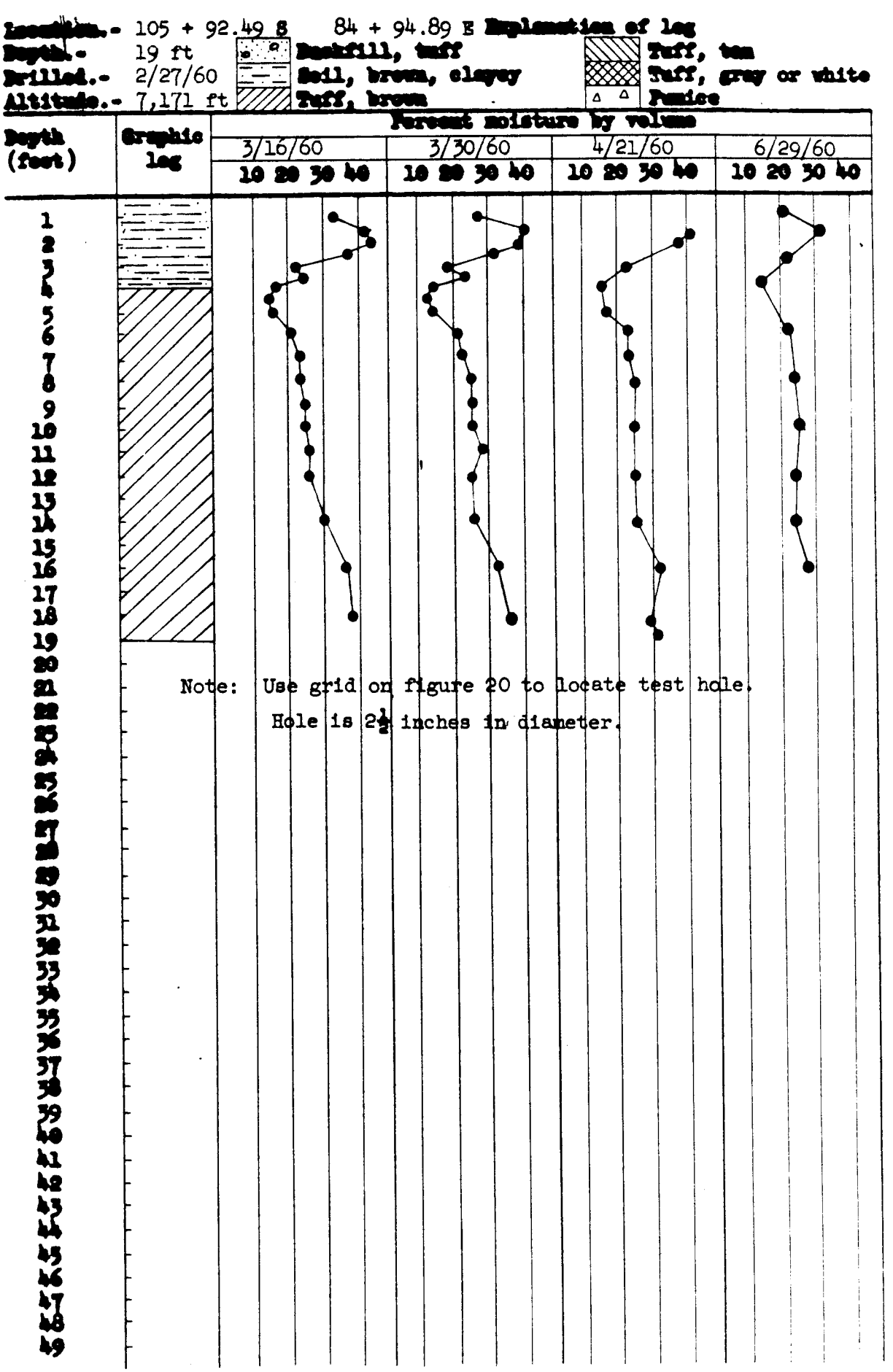


Figure 37.--Graph of moisture content and lithology in test hole
TM-2A, TA-49, Los Alamos County, N. Mex.

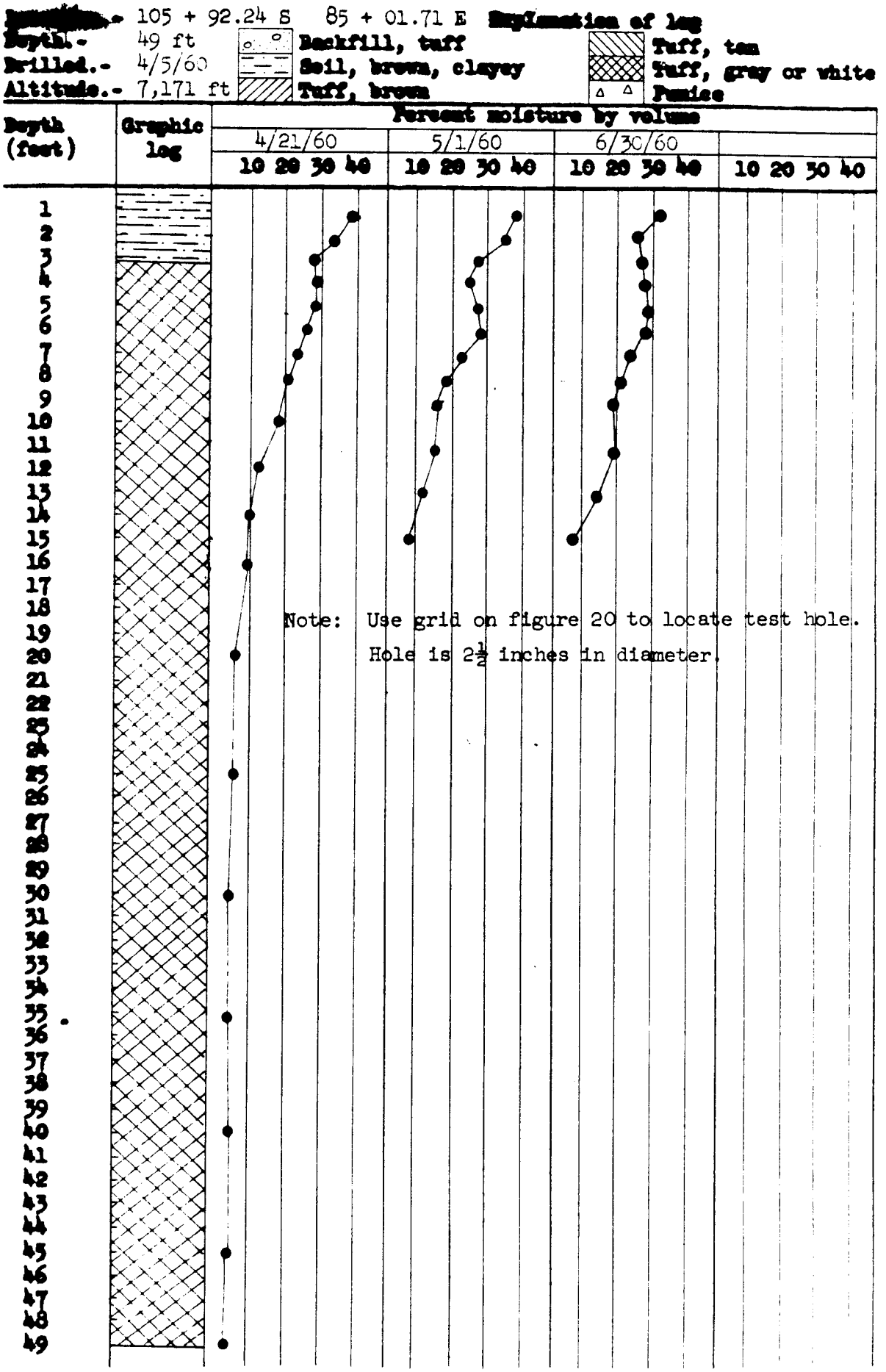


Figure 38.--Graph of moisture content and lithology in test hole 2M-3, TA-49, Los Alamos County, N. Mex.

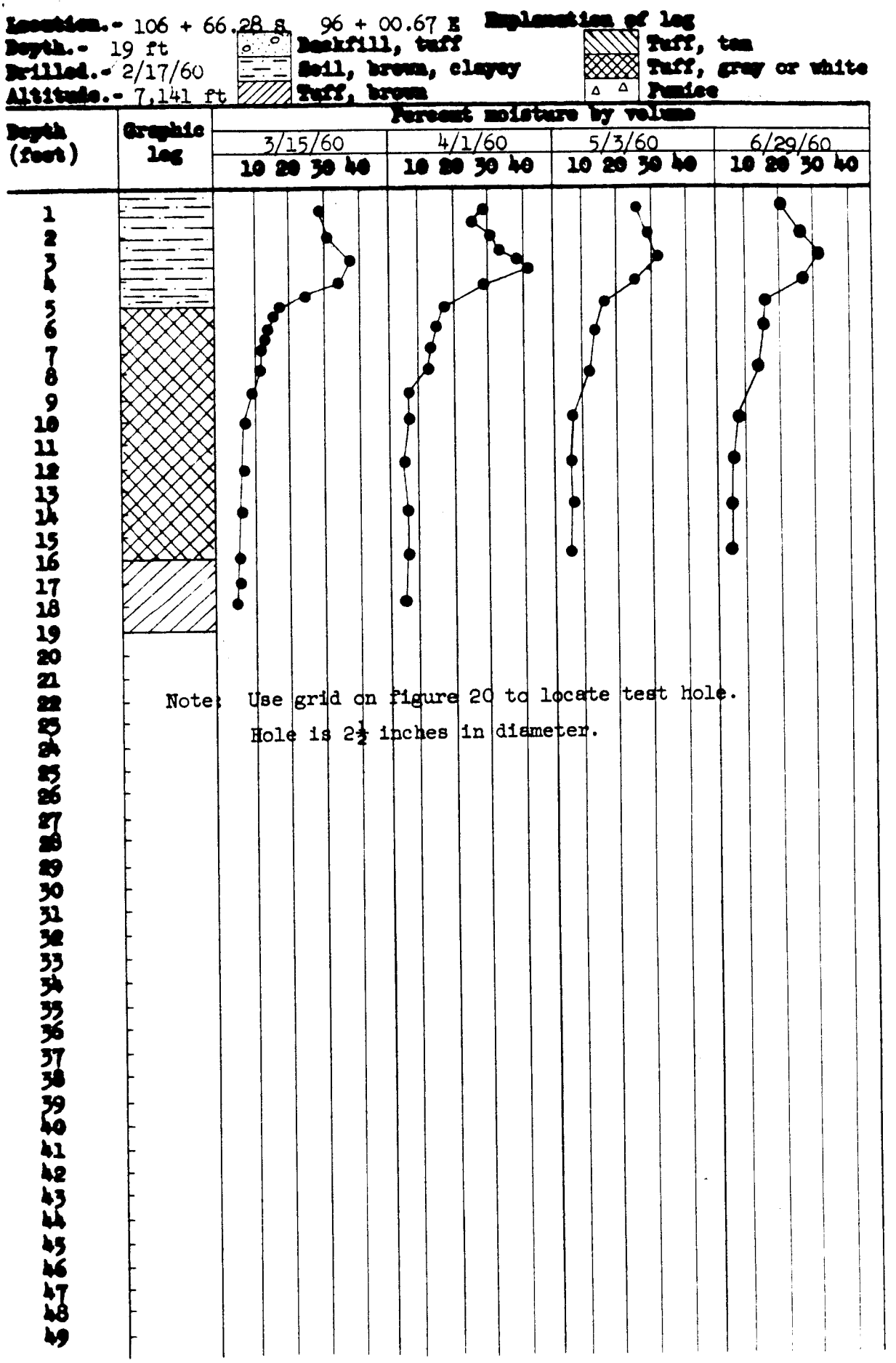


Fig. no 30.--Graph of moisture content and lithology in test hole M-1, TA-[illegible], Los Alamos County, N. Mex.

**Location.-** 111 + 31.61 S 94 + 35.54 E
**Depth.-** 39 ft
**Drilled.-** 2/16/60
**Altitude.-** 7,136 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice

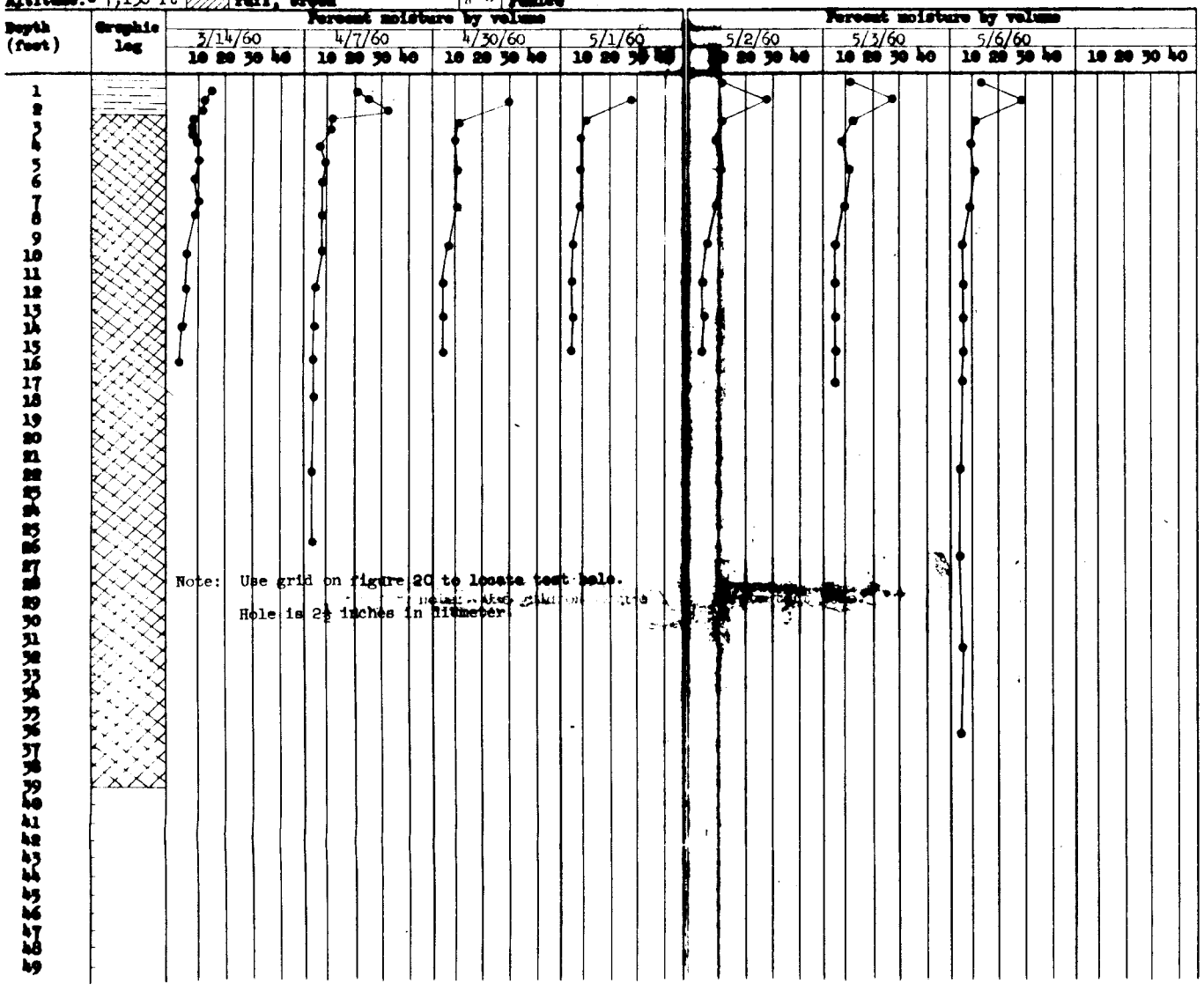
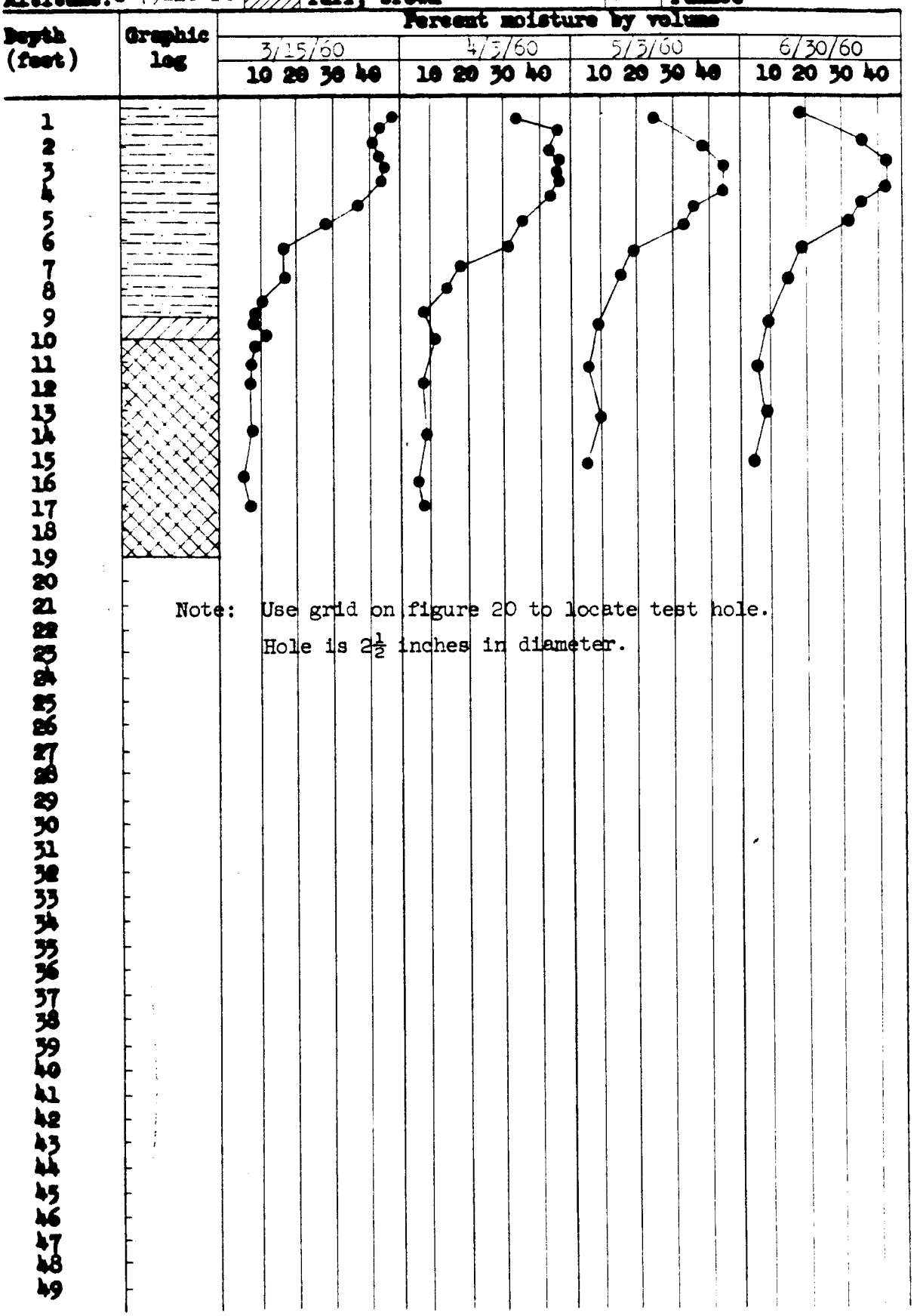


Figure 40.--Graph of moisture content and lithology in test hole 6M-1, TA-49, Los Alamos County, N. Mex.

**Location.-** 102 + 14.74 S 68 + 83.02 E
**Depth.-** 19 ft
**Drilled.-** 2/24/60
**Altitude.-** 7,210 ft

**Explanation of log**

- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice

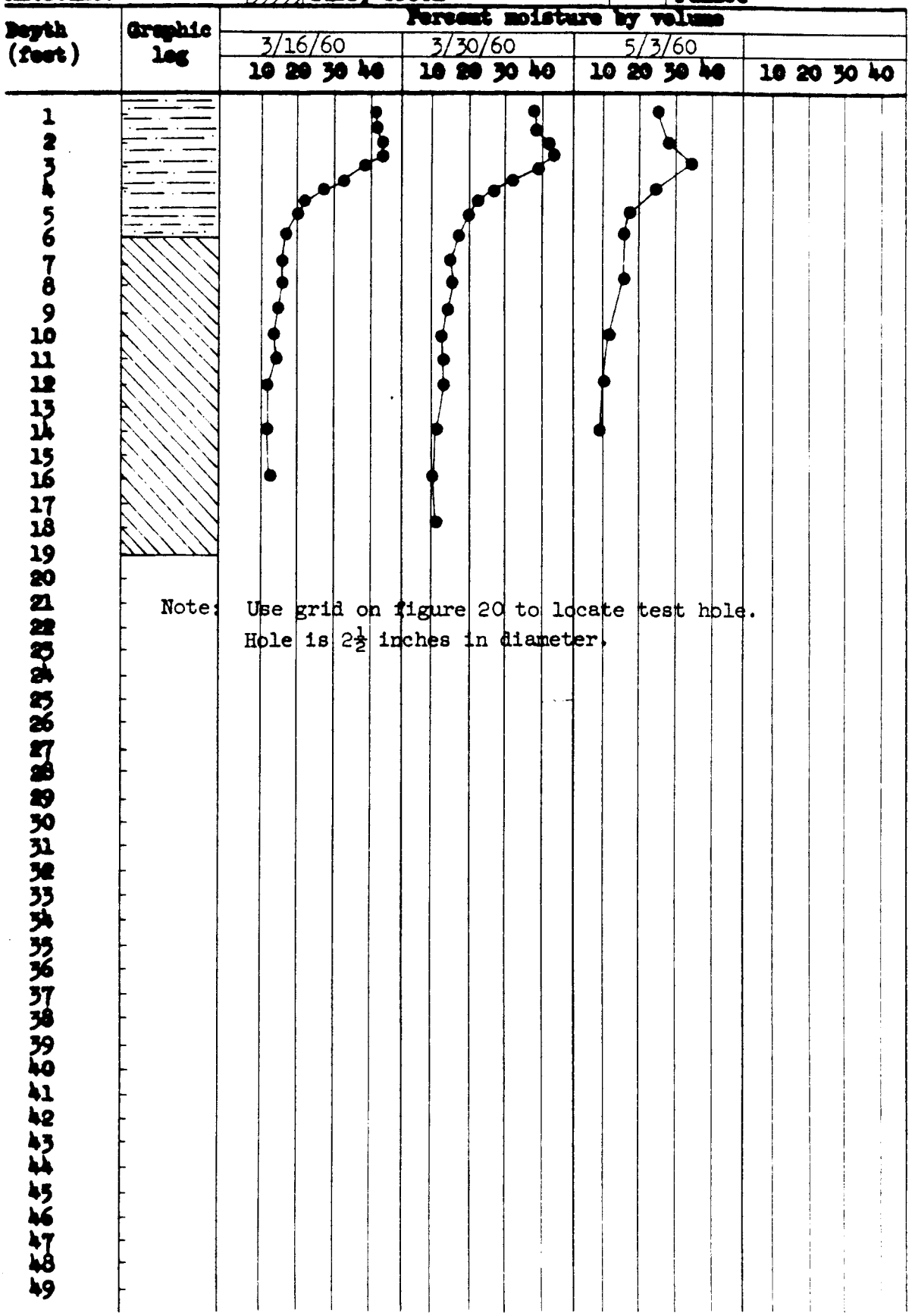



Note: Use grid on figure 20 to locate test hole.
Hole is $2\frac{1}{2}$ inches in diameter.

Figure 41.--Graph of moisture content and lithology in test hole 9M-1, TA-49, Los Alamos County, N. Mex.

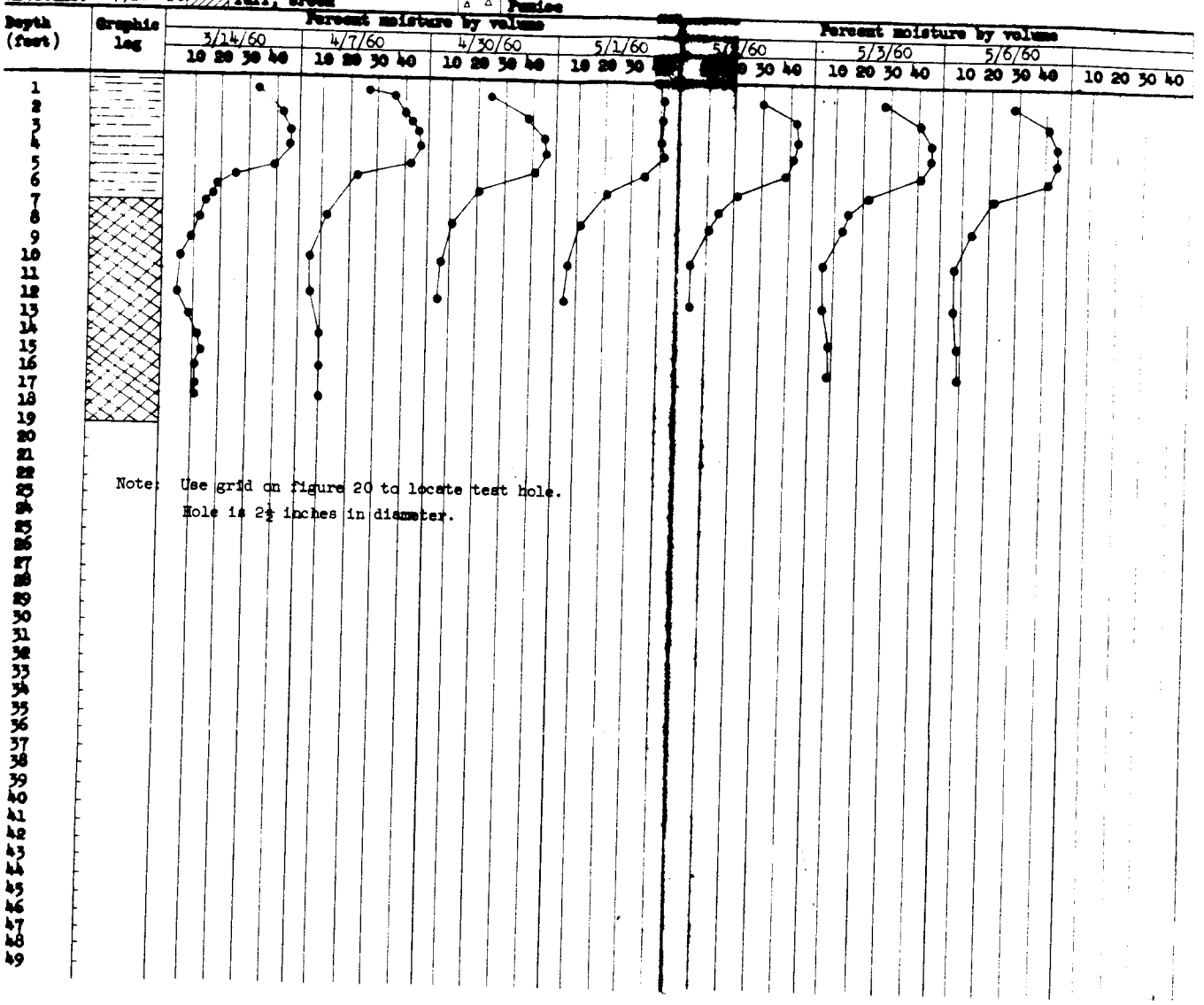
**Location.**- 116 + 67.49 S 88 + 43.84 E
**Depth.**- 19 ft
**Drilled.**- 2/24/60
**Altitude.**- 7,115 ft

**Explanation of log**
- Backfill, tuff
- Soil, brown, clayey
- Tuff, brown
- Tuff, tan
- Tuff, gray or white
- Pumice



Location.- 113 + 40.39 S 98 + 14.81 E Explanation of log
Depth.- 19 ft
Drilled.- 3/4/60
Altitude.- 7,104 ft

Backfill, tuff
Soil, brown, clayey
Tuff, brown
Tuff, tan
Tuff, gray or white
Pumice

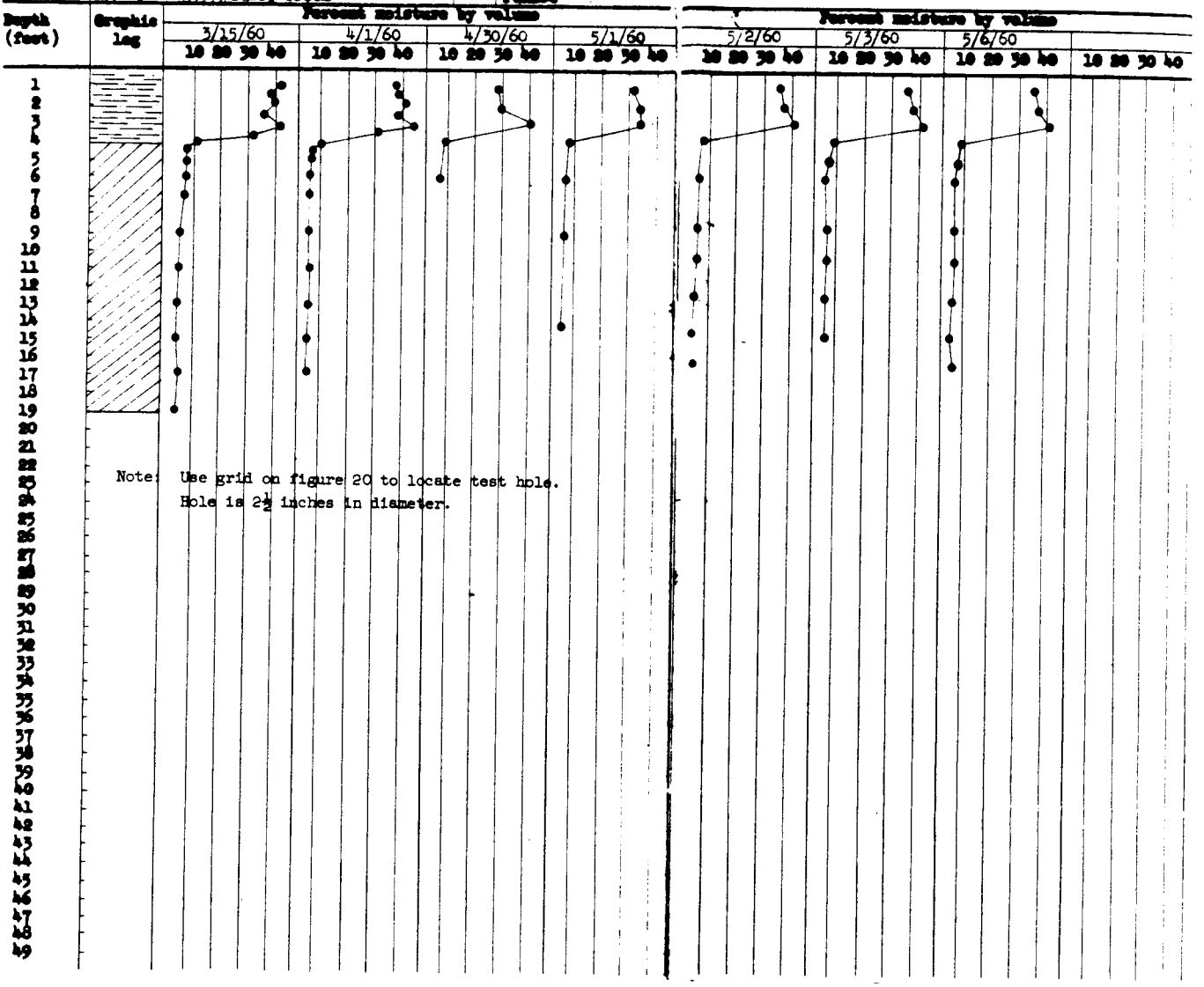



Note: Use grid on figure 20 to locate test hole.
Hole is 2½ inches in diameter.

Figure 43.--Graph of moisture content and lithology in test hole 9M-3, TA-49, Los Alamos County, N. Mex.

**Location.-** 117 + 01.80 S 104 + 56.98 E **Explanation of log**
**Depth.-** 19 ft
**Drilled.-** 2/17/60
**Altitude.-** 7,049 ft

Backfill, tuff
Soil, brown, clayey
Tuff, brown
Tuff, tan
Tuff, gray or white
Pumice




Note: Use grid on figure 20 to locate test hole.
Hole is 2½ inches in diameter.

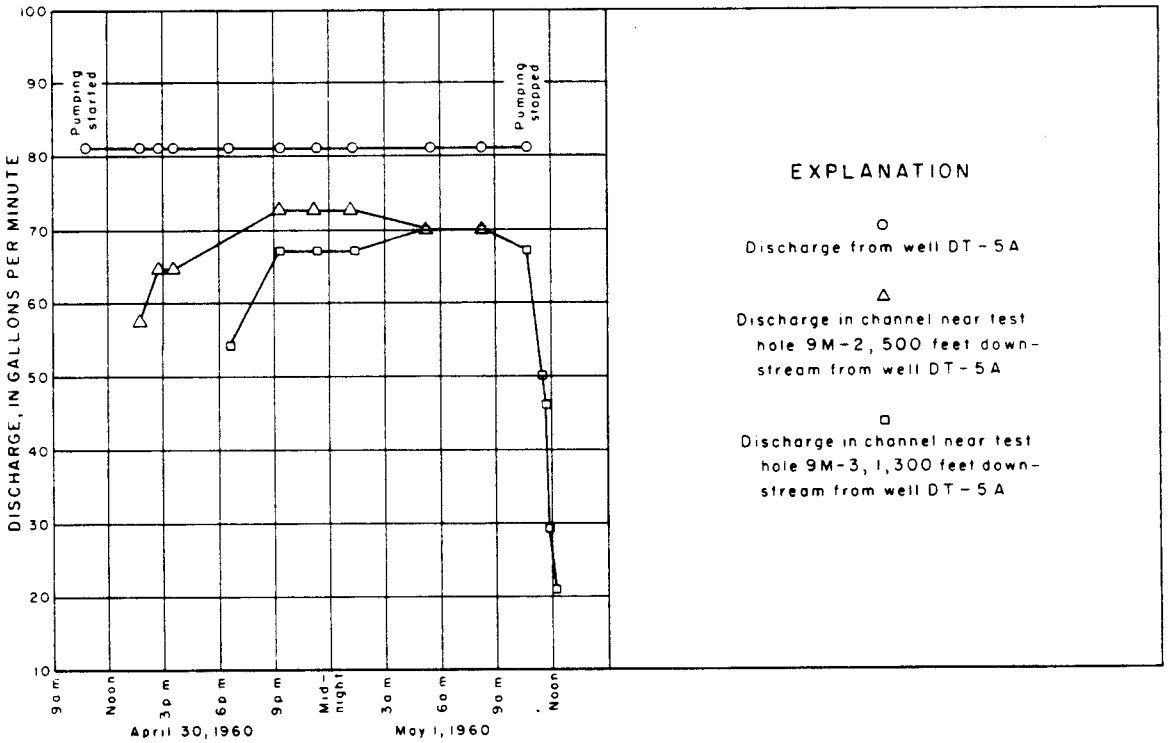
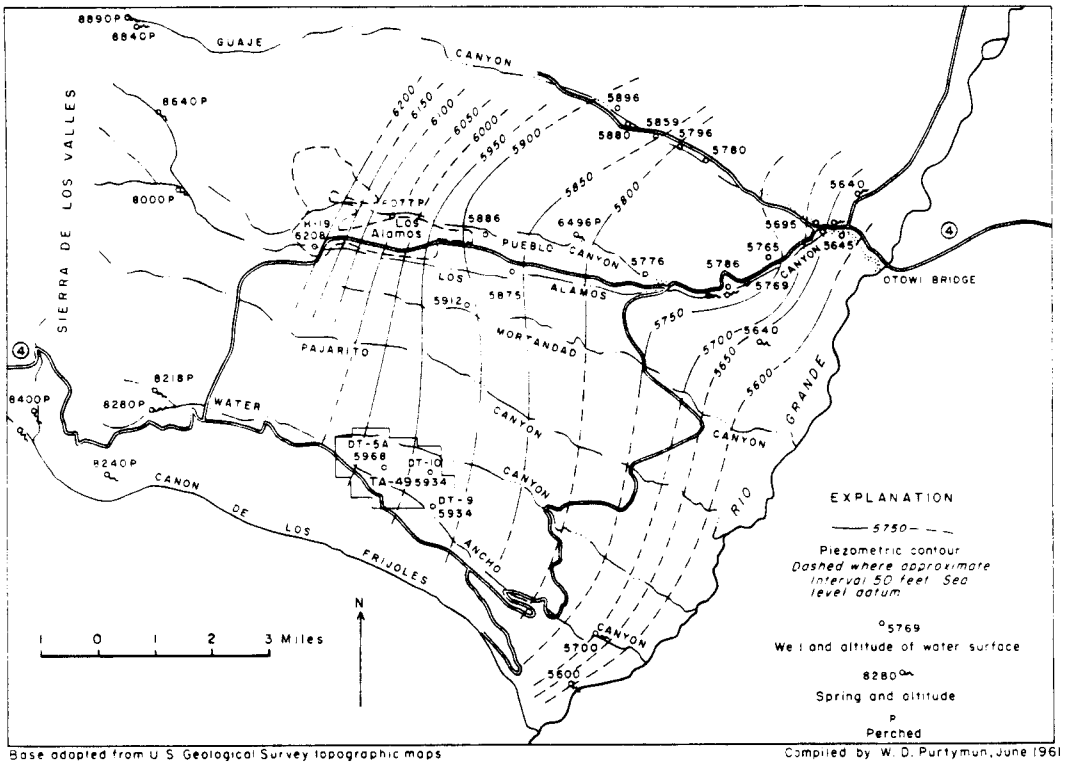



Figure 44.--Graph of measurements of flow downstream from well DT-5A as compared to discharge at well during pumping test April 30-May 1, 1960 at TA-49.




Base adapted from U S Geological Survey topographic maps

Compiled by W. D. Purtymun, June 1961

**Figure 45.--Generalized contours on the piezometric surface of the main aquifer, Los Alamos area, N. Mex.**

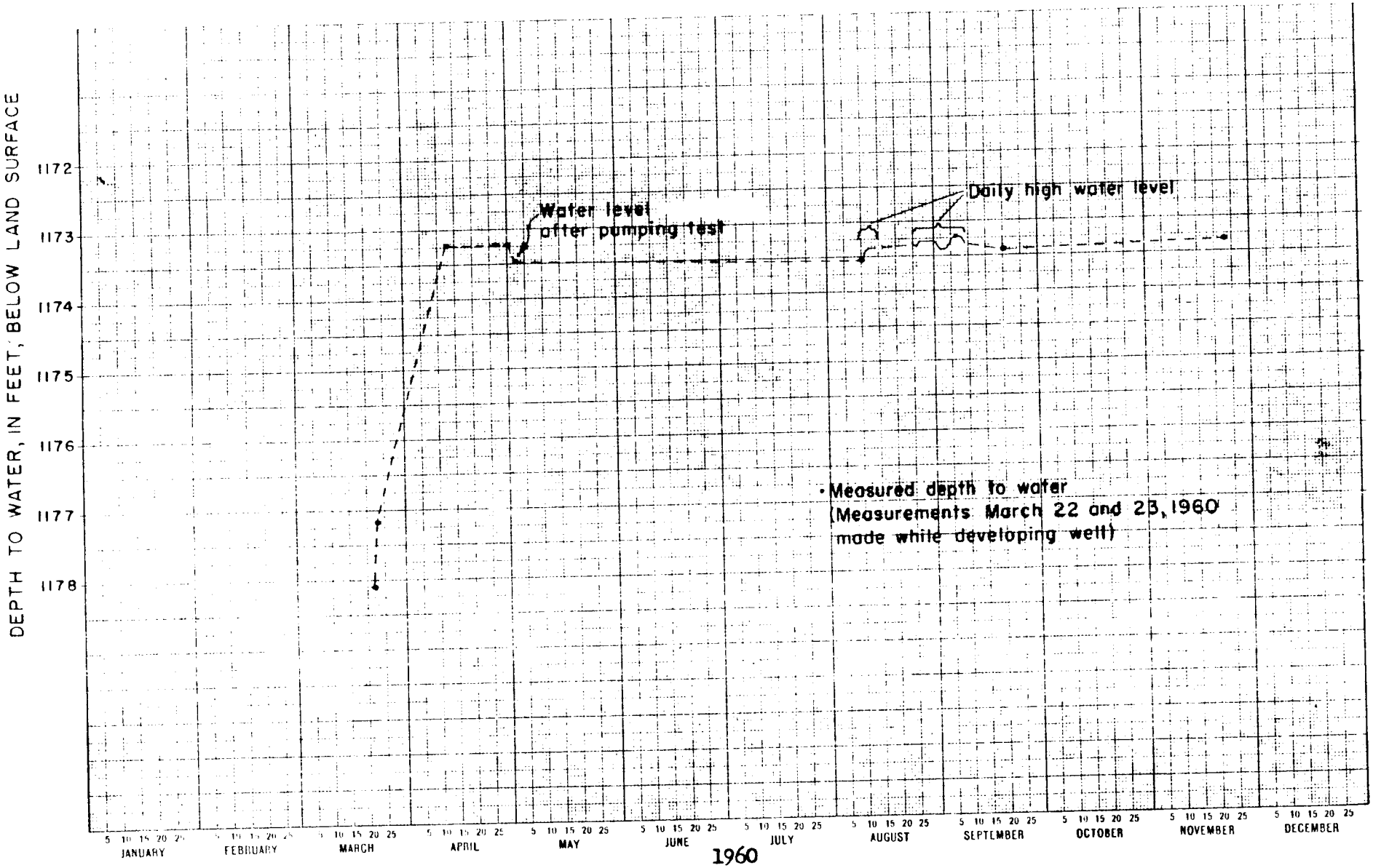



Figure 46.--Hydrograph of water levels measured and from recorder charts at well DT-5A, TA-49, Los Alamos County, N. Mex.

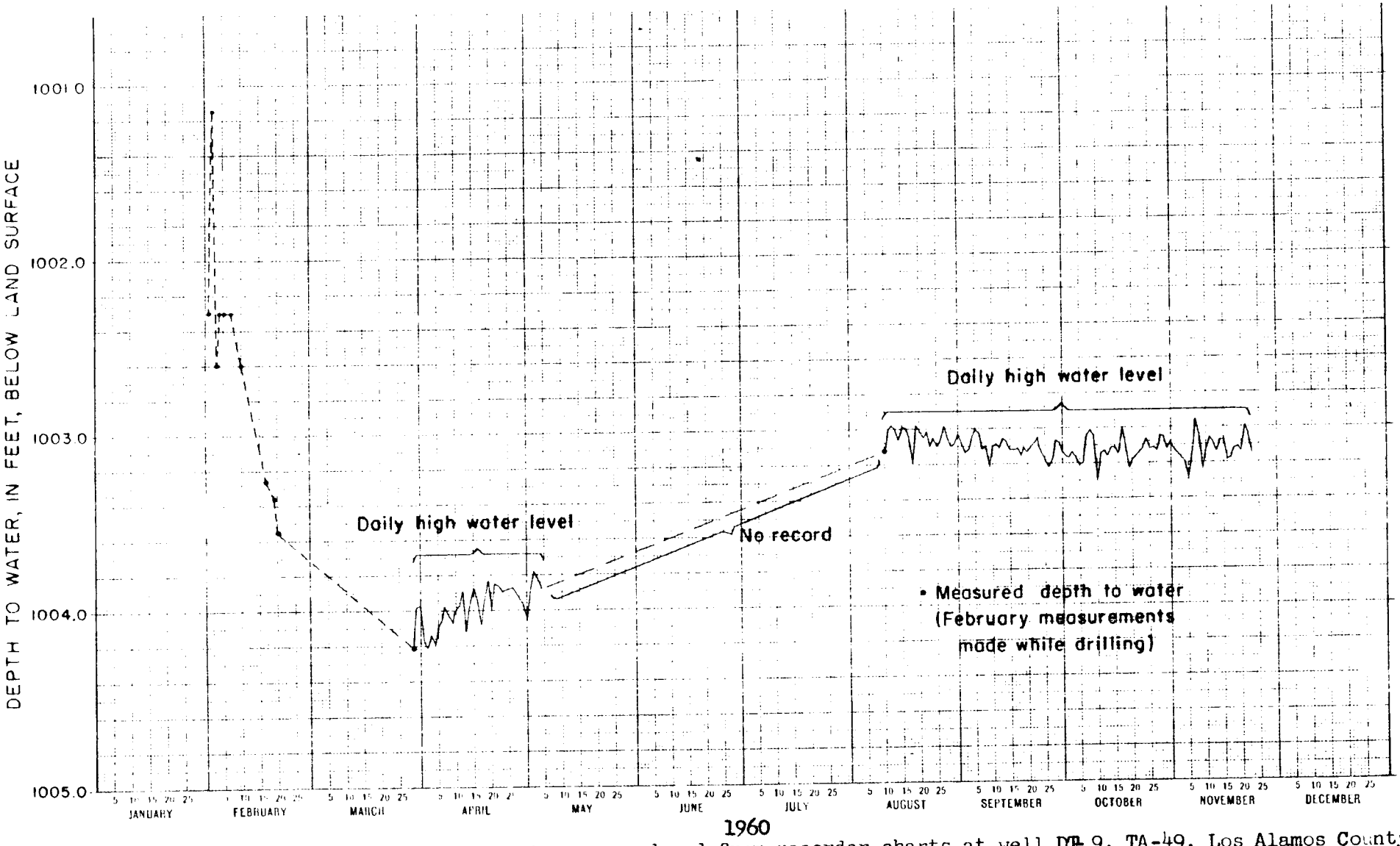



Figure 47.--Hydrograph of water levels measured and from recorder charts at well DP 9, TA-49, Los Alamos County, N. Mex.

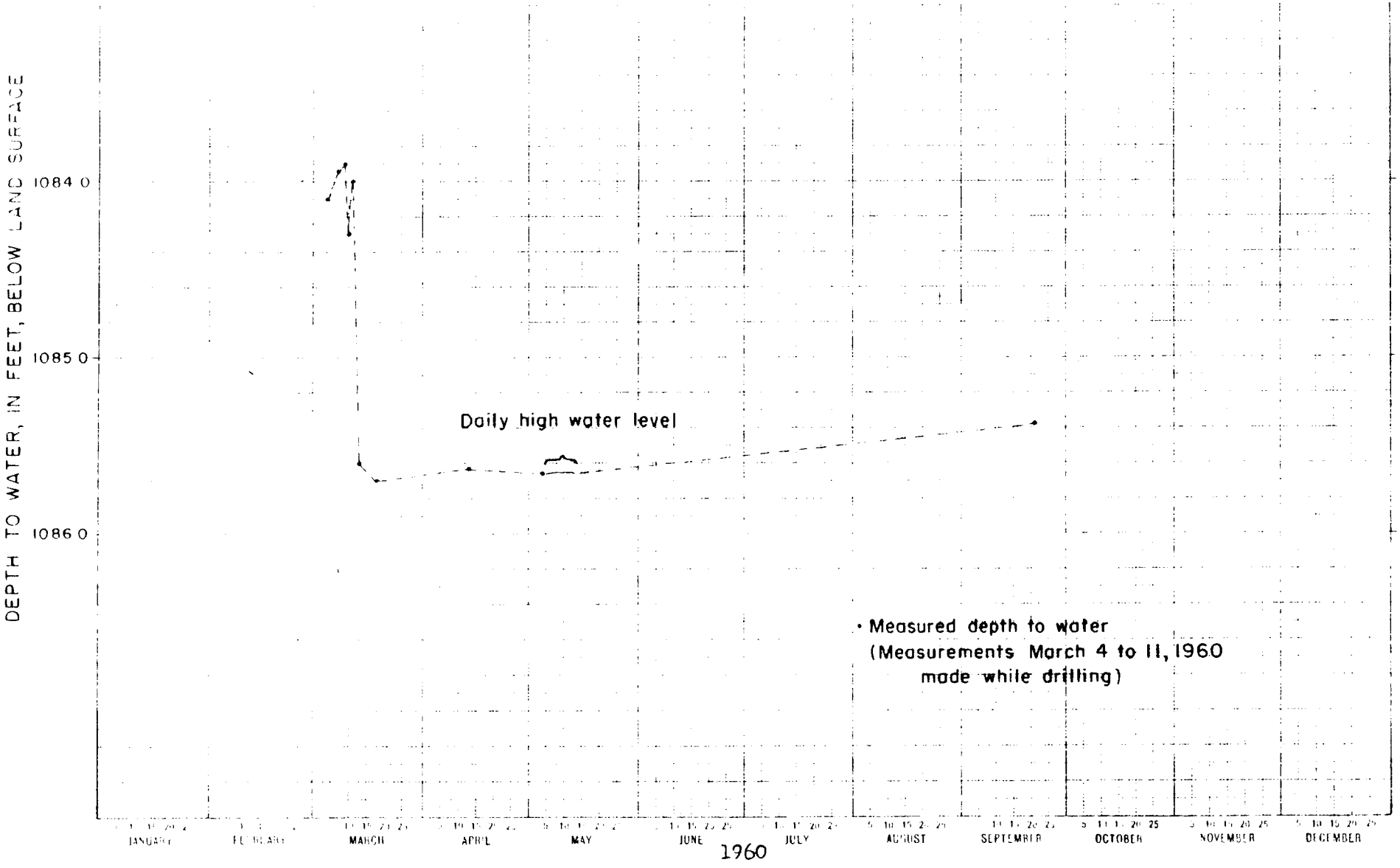



Figure 48.--Hydrograph of water levels measured and from recorder charts at well DT-10, TA-49, Los Alamos County, N. Mex.

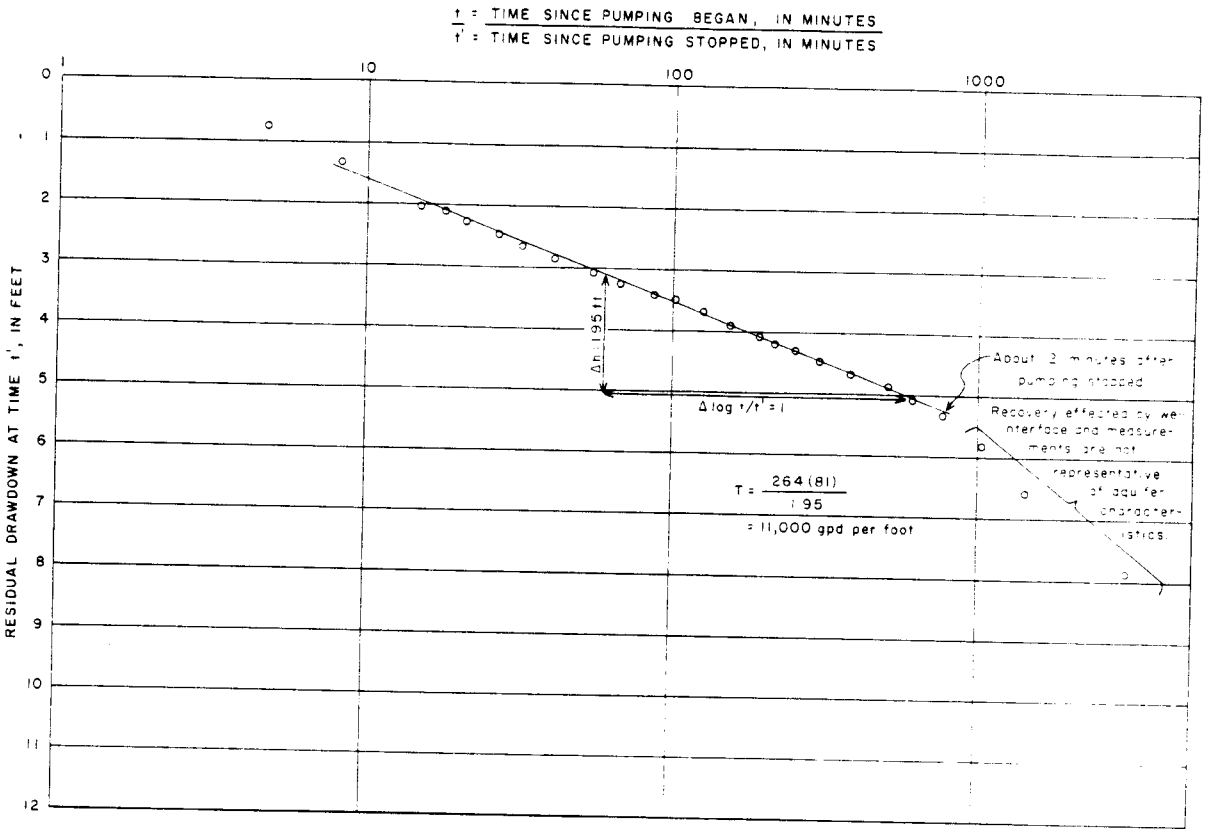



Figure 51.--Semilogarithmic graph of recovery of water level in well DT-5A May 1 and 2, 1960, after pumping 25 hours at an average of 81 gpm.

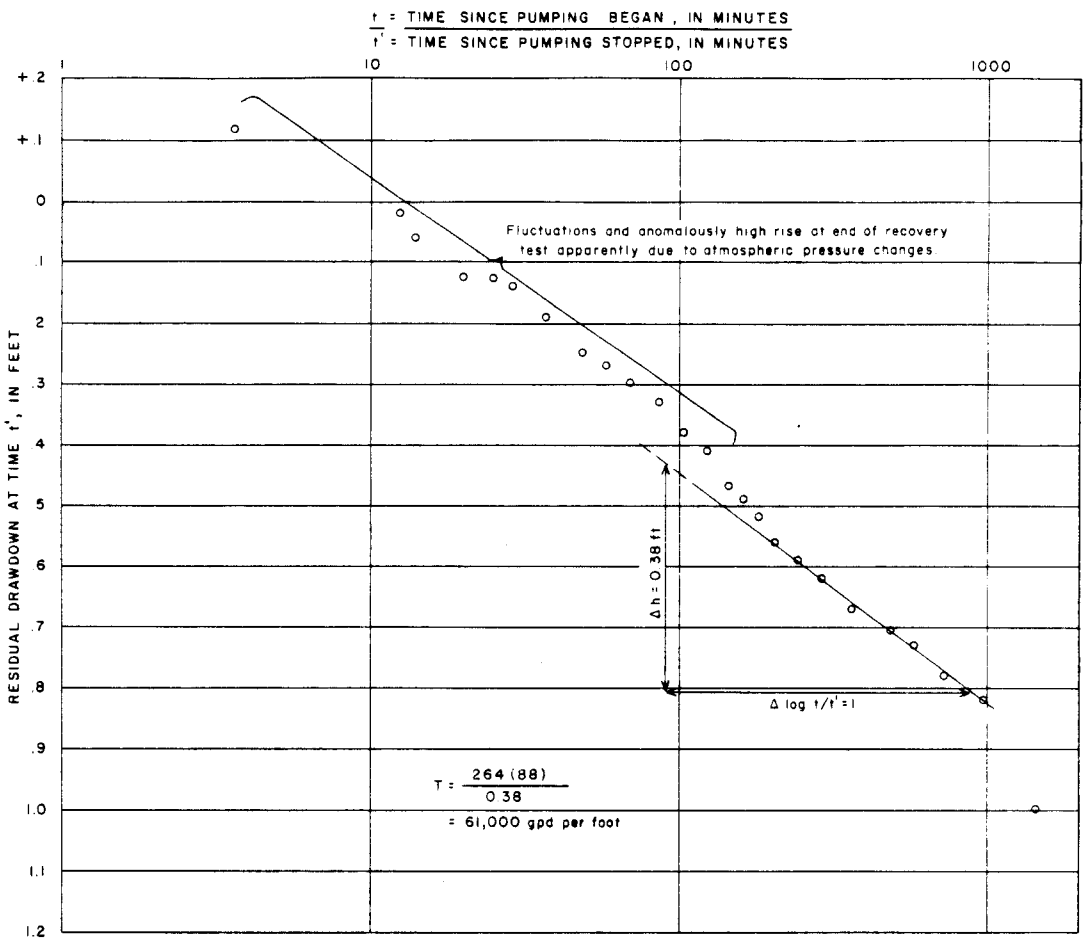



**Figure 52.--Semilogarithmic graph of recovery of water level in well DT-9 May 7 and 8, 1960, after pumping 24 hours at an average rate of 88 gpm.**

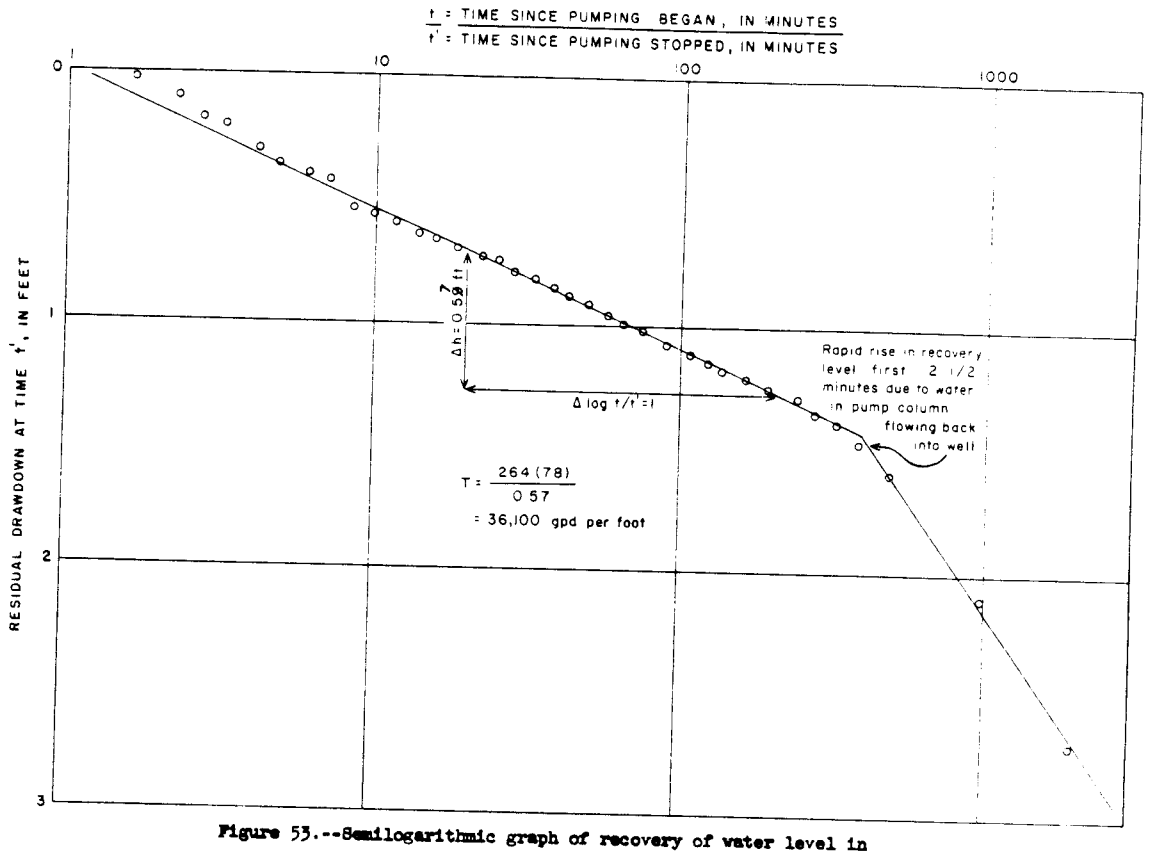



Figure 53.--Semilogarithmic graph of recovery of water level in well DT-10, September 22 and 23, 1960, after 16 hours of pumping at an average rate of 78 gpm.