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Preliminary report on the geology and hydrology of Mortandad Canyon near Los Alamos, N. Mex., with reference to disposal of liquid low-level radioactive waste

By

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Prepared in cooperation with the U.S. Atomic Energy Commission
and the Los Alamos Scientific Laboratory,
University of California

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Abstract

The U.S. Geological Survey, in cooperation with the U.S. Atomic Energy Commission and the Los Alamos Scientific Laboratory, selected the upper part of Mortandad Canyon near Los Alamos, N~~ew~~ Mex~~ico~~ for a site for disposal of treated liquid low-level radioactive waste. This report summarizes the part of a study of the geology and hydrology that was done from October 1960 through June 1961. Additional work is being continued.

Mortandad Canyon is a narrow east-southeast-trending canyon about $9\frac{1}{2}$ miles long that heads on the central part of the Pajarito Plateau at an altitude of about 7,340 feet. The canyon is tributary to the Rio Grande. The drainage area of the part of Mortandad Canyon that was investigated is ~~about~~ 2 square miles, and the total drainage area is ~~about~~ 4.9 square miles.

The Pajarito Plateau is capped by the Bandelier Tuff of Pleistocene age. Mortandad Canyon is cut in the Bandelier, and alluvium covers the floor of the canyon to depths ranging from less than 1 foot to as much as 100 feet. The Bandelier is underlain by silt, sand, conglomerate, and interbedded basalt of the Santa Fe Group of Miocene, Pliocene, and Pleistocene (?) age. Some ground water is perched in the alluvium in the canyon; however, the top of the main aquifer is in the Santa Fe Group at a depth of about 990 feet below the canyon floor.

Joints in the Bandelier Tuff probably were caused by shrinkage of the tuff during cooling. The joints range in width from hairline cracks to fissures several inches wide. Water can infiltrate along the open joints where the Bandelier is at the surface; however, soil, alluvial fill, and autochthonous clay inhibit infiltration on the tops of mesas and probably in the alluvium-floored canyons also.

Thirty-three test holes, each less than 100 feet deep, were drilled in 10 lines across Mortandad Canyon from the western margin of the study area to just west of the Los Alamos-Santa Fe County line. Ten of the holes were cased for observation wells to measure water levels and collect water samples from the alluvium. Twenty-three of the holes were cased to seal out water and were used as access tubes to accomodate a neutron-neutron probe for determining the moisture content of the alluvium and tuff.

The source of recharge for the perched ground-water body in the alluvium in Mortandad Canyon is the precipitation in the drainage area of the canyon. During the winter of 1960-61, a snowpack 1-2 feet thick accumulated in the narrow shaded upper part of the canyon. The alluvium beneath the snowpack received some recharge because of diurnal melting during the winter. In March 1961 the snowmelt water saturated most of the thin alluvium in the upper part of the canyon, and a ~~surface~~ stream began to flow on the alluvium. The maximum flow of the ~~surface~~ stream was about 250 gpm (gallons per minute). Water from the stream infiltrated into the alluvium at the front of the ~~surface~~ stream and in the reach upstream from the front. A ground-water mound was formed beneath the channel by water infiltrating from the stream. The front of the ~~surface~~ stream and the front of the ground-water mound advanced eastward to about the middle of the area studied. From this point eastward, the alluvium ~~is~~ was thick enough to absorb and transmit the amount of flow in 1961. Late in April the front of the ~~surface~~ stream retreated, and by the first of May the ~~surface~~ flow stopped. During and after this period the ground-water mound decayed, and ground-water levels ~~dropped~~ declined in the upper part of the canyon as water drained into the channel and downgradient through the alluvium.

The amount of recharge was small in the wide lower part of the canyon during the period of study. The rise in ground-water levels and the increase in moisture content of the alluvium in the lower part of the canyon indicate that water moved downgradient by underflow through the alluvium from the recharge area in the upper part of the canyon. Moisture measurements indicate that only a little water moved into the underlying Bandelier Tuff from the saturated alluvium in the part of the canyon studied.

A deep test well was drilled in Mortandad Canyon near the middle of the area studied. The top of the main aquifer in the well was between the depths of 985 and 990 feet below the bottom of the canyon. The water rose almost 30 feet in the well, indicating ~~that~~ confining beds ~~exist~~ in the lower part of the Puye Conglomerate. The piezometric surface of the main aquifer slopes eastward, indicating that the main aquifer is recharged mainly west of the Pajarito Plateau, and that it discharges the water near the Rio Grande. Samples of water from the main aquifer and the alluvium had no radioactivity above that of a standard sample of water.

The infiltration and movement of waste liquid will follow the same general pattern as that of the perched ground water in the alluvium. The liquid will infiltrate in the upper and middle reaches of the part of the canyon studied and move eastward through the alluvium. The data indicate that the alluvium in the lower reach will absorb and transmit the predicted discharge of 500,000 gallons of waste per week. Little of the liquid will move downward into the Bandelier Tuff in the area studied, and probably none will reach the main aquifer in the Santa Fe Group. The movement of ground water in the part of the canyon east of the Los Alamos-Santa Fe County line was not determined.

The clay in the alluvium probably will remove most of the radioactive waste material by sorption and base exchange. This might eventually build up relatively high concentrations of radioactive material which would move slowly downgradient through the alluvium. Further work will be necessary, before and after waste is discharged from the plant, to obtain quantitative hydrologic data and to determine the movements of the water in the alluvium below the area studied.

Introduction

Untreated liquid radioactive waste from the Los Alamos Scientific Laboratory was discharged into deep canyons at Los Alamos, N. Mex. before 1951. Since 1951, only wastes that were treated to off-site tolerances have been discharged. Much of the treated liquid radioactive waste has been discharged into canyons within or adjacent to the residential area of the city, although most of the technical areas creating the wastes are south of the townsite. Since 1950 the U.S. Geological Survey, in cooperation with the U.S. Atomic Energy Commission and the Los Alamos Scientific Laboratory, has been studying the general geology and hydrology of the Los Alamos area and ~~conducting~~ making special studies ~~on~~ of the underground movements of waste materials to determine the contamination hazard involved in the discharge of radioactive wastes. The laboratory requested that the Geological Survey assist in selecting a site suitable for the discharge of liquid low-level radioactive wastes from a proposed new treatment plant to be located outside the city.

Mortandad Canyon, about a mile south of the city, was selected because of its relatively isolated position on the Pajarito Plateau, its small drainage area, and the relatively large amount of alluvium in the canyon. The small drainage area reduces the possibility of large floods, and the large amount of alluvium insures a large underground storage space for liquid waste. The Atomic Energy Commission at Los Alamos selected a site for a proposed waste-treatment plant on the plateau between two canyons tributary to upper Mortandad Canyon.

Purpose and scope of investigation

The geology and hydrology of part of Mortandad Canyon are being studied to determine the movement and destination of natural surface water and ground water in the canyon as a basis for predicting the movements of the liquid waste that will be discharged into the canyon. The new waste-disposal plant initially will discharge ~~about~~ from 60,000 to 70,000 gpd (gallons per day) of low-level radioactive liquid waste into Effluent Canyon, which is a tributary of Mortandad Canyon. The discharge will be increased to 100,000 gpd, and the predicted ultimate discharge may be as much as 300,000 gpd. A discharge of 100,000 to 300,000 ~~gallons per day~~ gpd is equivalent to a uniform rate of discharge of 70 to 210 gpm (gallons per minute); however, the discharge probably will be in slugs, with two slugs being discharged in each 8-hour period. The rate of discharge of each slug will range from 200 to 250 gpm.

Data are being collected to determine whether the alluvium and bedrock in the canyon will absorb and transmit the predicted normal quantity of treated waste and whether the alluvium and bedrock will absorb accidental rapid discharges of untreated or partly treated waste. Data were collected also in an attempt to determine whether the perched ground water in the alluvium moves downward through the bedrock toward the main zone of saturation, moves by underflow toward the Rio Grande, or is dissipated by evaporation and transpiration from the alluvium. The underground path of low-level radioactive liquid wastes must be traced in order to determine whether there is a possibility of contaminating public or private ground-water supplies.

Field work for this report was done in two phases. The first phase consisted of constructing 10 shallow observation wells, 23 shallow moisture-measurement access tubes, and a deep test well. The shallow wells and access tubes were constructed in October and November 1960, and the deep test well was constructed in November and December 1960. The shallow observation wells and moisture-measurement access tubes were constructed to study the water perched in the alluvium in the zone of aeration. The deep test well was drilled to study the subsurface geology and to determine the top of the main zone of saturation ~~which constitutes the main aquifer in the Los Alamos area~~. Water samples were collected from the main aquifer to be analyzed for radiological and chemical background data. A record~~er~~ing gage was installed on the well to record fluctuations of the water table. A bailing test provided data ~~about~~ concerning the water-transmission characteristics of the main aquifer. The well will be used in the future for monitoring for radioactivity and for a water-supply well, if needed.

The second phase of field work, from April through June 1961, consisted of geologic mapping, collecting water samples from the shallow wells for radiometric analysis, ~~making~~ measur~~ements of~~ing the moisture content of the alluvium and bedrock, and collecting data concerning the movements of surface water and ground water. Samples of the bedrock and alluvium were collected for analysis to determine the natural background radiation levels and to estimate the degree of retention of residual radioactive material in the alluvium and bedrock.

The present report summarizes the work completed and the basic data obtained from October 1960 through June 1961. The work done during this period helped to determine the nature of additional work and changes in procedures of data collection. The collection and interpretation of data will be continued, and a final report will be prepared after the effects of waste discharge are known.

Acknowledgments and personnel

Early studies to locate a site suitable for the long-term discharge of radioactive wastes at Los Alamos were ~~conducted~~ made by C. W. Christenson and W. R. Kennedy of ~~LASL~~ (Los Alamos Scientific Laboratory), and J. H. Abrahams, Jr. of the Geological Survey. Aiding in these investigations were personnel of the Engineering Division of LASL and the Engineering and Construction Division of the ~~AEC~~ (Atomic Energy Commission).

Mr. T. W. Roehl of the U.S. Atomic Energy Commission was in charge of contracts for construction and was helpful in many ways. Mr. J. F. Hill of the Zia Company was construction supervisor for building roads and obtained materials for the deep test well. Mr. S. E. Russo of the Los Alamos Scientific Laboratory provided surveying data and maps. The topographic base map and aerial photographs used in mapping were obtained by the Atomic Energy Commission from Limbaugh Aerial Surveys, Inc. Mr. Pablo Romero of the Los Alamos Scientific Laboratory assisted in the collection of some of the hydrologic data.

R. Kanawyer of the Hydrologic Laboratory of the U.S. Geological Survey drilled the shallow holes, and was assisted in the construction of the wells by J. E. Weir, Jr., W. D. Purtymun, G. C. Doty, and W. C. Ballance. J. E. Weir, Jr., W. D. Purtymun, and G. A. Dinwiddie supervised the collection of drill cuttings samples from the deep test well. The geology was mapped by E. H. Baltz, and the hydrologic data and samples were collected by J. H. Abrahams and W. D. Purtymun.

Geography

Mortandad Canyon is a narrow east-southeast-trending canyon ~~about~~ 9½ miles long on the Pajarito Plateau in Los Alamos and Santa Fe Counties, ~~New Mexico~~ (fig. 1). The head of the canyon

Figure 1.--Index map of New Mexico showing Los Alamos County.

is ~~about~~ three-fourths of a mile south of Los Alamos in the western part of the plateau, and the mouth is in White Rock Canyon of the Rio Grande at the east side of the plateau (fig. 2).

Figure 2.--Geologic map of part of Mortandad Canyon, Los Alamos, Sandoval, and Santa Fe Counties, N. Mex.

The altitude near the head of Mortandad Canyon is ~~about~~ 7,300 feet. One ~~About 1~~ mile west of the Rio Grande, Mortandad Canyon drops from an altitude of ~~about~~ 6,300 feet to ~~about~~ 5,440 feet at the Rio Grande. Four small eastward-draining tributary canyons enter Mortandad Canyon from the south, and the total drainage area of the canyon and its tributaries west of White Rock Canyon is ~~about~~ 4.9 square miles. Two of these tributary canyons, Ten Site and Effluent Canyons, are of particular concern in this investigation. Most of the area studied is in the upper part of Mortandad Canyon west of the Los Alamos-Santa Fe County line.

Near the Los Alamos-Santa Fe County boundary the canyon floor is relatively flat and is 600 to 700 feet wide. The canyon is narrower to the west, and, in the vicinity of test well 8 (TW-8) near the center of sec. 23, T. 19 N., R. 6 E., the floor of the canyon is only about 100 feet wide. West of well TW-8 the canyon bottom is 30 to 80 feet wide and in many places is boulder strewn and irregular. The canyon walls are steep and in some places are nearly vertical.

At most places in the study area the ~~slope of the~~ north wall of the canyon is steeper than ~~that of~~ the south ~~wall~~. The north wall is mainly bare rock with scanty vegetation, whereas talus and soil partly cover the rocks of the south wall and support a relatively dense growth of deciduous shrubs and conifers. Presumably, the differential erosion of the canyon walls has resulted partly from differing vegetative cover, which, in turn, is the result of differing amounts of solar radiation received by the north and south walls.

Stands of large ponderosa pine interspersed with junipers and pinon pine grow on the floor of the canyon in the eastern part of the study area. The floor of the canyon in sec. 24, T. 19 N., R. 6 E. is mainly a meadow with sparse grass and scattered large ponderosa pines. The narrow upper part of the canyon contains relatively dense stands of spruce and ponderosa pine, deciduous trees and shrubs, herbs and grass.

The middle part of Ten Site Canyon and the lower part of Effluent Canyon are narrow and steep walled and have irregular, boulder-strewn bottoms. The upper parts of these tributary canyons are relatively broad and contain only a few thin patches of alluvium and soil resting on bedrock.

Geology

General discussion

Mortandad Canyon is on the Pajarito Plateau, which is capped by rhyolitic volcanic rocks of the Bandelier Tuff of Pleistocene age. The Bandelier is subdivided into three members (Griggs, ~~in press~~ ~~1955)~~. 1962, p.84. In ascending order these are: the Guaje Member composed of gravel-sized pumice; the Otowi Member composed of slightly welded pumiceous ash with some beds of tuff breccia; and the Tshirege Member composed of welded pumiceous ash, crystal-fragment tuff, and tuff breccia.

Over most of the plateau area the Bandelier Tuff rests unconformably on the Santa Fe Group of Miocene, Pliocene, and Pleistocene (?) age. The lower part of the Santa Fe Group consists of sand, silt, clay, and some interbedded gravel called the "undifferentiated unit of the Santa Fe Group," by Griggs ~~(in press~~ ~~1955)~~, (1962, p.37) and the Tesuque Formation by Spiegel and Baldwin (in press). No wells have been drilled to the base of the Tesuque Formation on the Pajarito Plateau, thus the nature of the rocks below the Santa Fe Group in this area is unknown. The Tesuque Formation is overlain unconformably by the Puye Conglomerate (Griggs, ~~in press~~ ~~1955~~ 1962, p.48) of the Santa Fe Group throughout most of the plateau. The Puye Conglomerate consists of the Totavi Lentil overlain by the fanglomerate member (Griggs, ~~in press~~ ~~1955)~~. 1962, p.51). The Totavi Lentil is a deposit of ancient river gravel composed of sand, pebbles, and boulders of quartzite, granite, and volcanic rocks. The fanglomerate member is composed of silt and sand and pebble to boulder breccia of volcanic rocks.

In the eastern part of the plateau the Totavi Lentil is overlain by thick flows of the basaltic rocks of Chino Mesa (Griggs, ~~1955~~ in press 1962, p. 54), which form the upper part of the Santa Fe Group in the vicinity of White Rock Canyon. The basaltic flows tongue out westward in the subsurface into the Fanglomerate member of the Puye Conglomerate.

In the western part of the Pajarito Plateau the Puye Conglomerate intertongues with and laps onto volcanic rocks of the Tschicoma Formation of ~~Miocene(?)~~ Pliocene and ~~Pliocene~~ Pleistocene (?) age, ~~that~~ which form much of the Sierra de los Valles west of the Pajarito Plateau. On the eastern flank of the Sierra de los Valles the Bandelier Tuff overlaps the Puye Conglomerate and rests on the Tschicoma Formation. The stratigraphic relations of the Santa Fe Group, Tschicoma Formation, and Bandelier Tuff are shown diagrammatically in figure 3.

Figure 3.--Diagrammatic cross section showing generalized stratigraphic relations of the Santa Fe Group, Tschicoma Formation, and Bandelier Tuff in the Los Alamos area.

The surface rocks at Mortandad Canyon are mainly the Tshirege Member of the Bandelier Tuff. (See geologic map, fig. 2.) The subsurface rocks ~~encountered~~ in test well 8 drilled in the NE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 23, T. 19 N., R. 6 E. are the Otowi and Guaje Members of the Bandelier, the Fanglomerate member of the Puye Conglomerate, and basalt flows of the basaltic rocks of Chino Mesa.

Stratigraphy

Puye Conglomerate

The Fanglomerate member of the Puye Conglomerate of Pliocene(?) age is the oldest stratigraphic unit penetrated ~~encountered in the subsurface~~ at test well 8 (fig. 4). It is present between the depth of 490

Figure 4.--Log and cross section of test well 8, Mortandad Canyon, Los Alamos County, N. Mex.

~~feet~~ and ~~the depth of~~ 1,065 feet, ~~which is~~ the ~~total~~ depth of the well. The well is bottomed in sediments that probably are only a short distance above the Totavi Lentil which is the basal unit of the Puye Conglomerate. Most of the Fanglomerate member consists of gravel, sand, silt, and clay, but volcanic flows of the basaltic rocks of Chino Mesa occur between the depths of 580 and 725 feet and split the Fanglomerate member into a main (lower) part and an upper part.

Between the depths of 970 and 1,065 feet, the main part of the Fanglomerate member consists of light-tan to light-gray tuff and tuffaceous pebbly sand. Most of the sand is composed of fine to coarse quartz and angular quartz-crystal fragments. Pebble fragments consist of pumice, basalt, rhyolite, and latite. Some of the material probably is water laid, as indicated by the rounding of the fragments. This unit is lithologically similar to a unit of the Fanglomerate member that consists of pumice and gravel 320 feet thick at test hole 2 in Pueblo Canyon, and 90 feet thick at test hole 3 in Los Alamos Canyon (fig. 11). Confined water was found ~~encountered~~ at test well 8 in the tuff and tuffaceous sand between the depths of 985 and 990 feet. The water rose in the hole to a depth of 962.6 feet below land surface, indicating that confining layers are present in the tuff and tuffaceous sand between the depths of 985 and 990 feet. The nature of the confining beds was not determined from the cuttings, but the beds are probably clay. The tuff and tuffaceous sand probably rest on the Totavi Lentil and may be connected hydraulically with it.

Above the tuffaceous unit, between the depths of 725 and 970 feet, the main part of the Fanglomerate member consists of sand, silt, and clay with abundant interbedded gravel composed of latite, rhyolite, basalt, and andesite fragments. No water was found in these beds, which are overlain by the basalt flows that split the Fanglomerate member.

The upper part of the Fanglomerate member, between the depths of 500 and 580 feet, is similar to the beds below the basalt. The highest beds of the upper part of the Fanglomerate member, in the interval between 490 and 500 feet below the surface, are light-tan slightly tuffaceous fine- to coarse-grained sand containing rhyolite and latite fragments. No water was found in the upper part of the Fanglomerate member. Water introduced into the hole during drilling and bailing of cuttings was perched at a depth of about 570 feet. Examination of cuttings from the interval 565 to 580 feet below land surface indicates that the perching layer is silty, sandy clay resting on the basalt. A bailing test indicated ~~that there was no~~ the absence of formational water in this interval.

Basaltic rocks of Chino Mesa

Several flows of brown and gray basalt are in the Fanglomerate member of the Puye between the depths of 580 and 725 feet. These rocks are hard, and the ground-up drill cuttings are mainly sand- and silt-sized fragments of greenish-gray glass and feldspar crystals ~~with~~ and a few larger fragments of black basalt. Yellowish-tan tuffaceous sand, which seems to be a bed of interflow sediments, occurs near the base of the unit from about 705 to 715 feet. ~~The basalts are correlated with flows that were mapped as unit 4 of the basaltic rocks of Chino Mesa by Griggs (1955, geologic map) and later (Griggs, in preparation) classified as unit 2.~~ No water was ~~encountered~~ found in these rocks in test well 8.

Bandelier Tuff

The Bandelier Tuff of Pleistocene lc Age is the surface formation in the Mortandad Canyon area and is present also in the subsurface, resting unconformably on the Puye Conglomerate. The Bandelier Tuff is rhyolitic and consists, in ascending order, of the Guaje Member, the Otowi Member, and the Tshirege Member (~~Griggs, 1955~~ in press). The Guaje Member is not exposed ~~at the surface~~ in Mortandad Canyon. An outcrop of gray pumiceous tuff tentatively identified as the upper part of the Otowi Member was observed in the eastern part of the area (fig. 2) in a road cut on New Mexico Highway 4.

Guaje Member

The Guaje Member was penetrated in test well 8 between the depths of 445 and 490 feet. It consists mainly of rounded fragments of white, gray, and tan pumice in a matrix of glassy ash. Sand-sized quartz and feldspar crystal fragments and pink and red rock fragments occur also in the pumice. No water was ~~encountered~~ found in the Guaje Member in test well 8.

Otowi Member

The Otowi Member rests on the Guaje Member and was penetrated in test well 8 between the depths of 60 and 445 feet. The Otowi Member consists of light-gray to light-tan and light-pinkish-tan pumiceous tuff, tuff breccia, and crystal-fragment tuff. Layers containing angular fragments of gray, red, and brown rhyolite and latite(?) fragments are common, and ~~there are~~ several layers ~~that~~ consist mostly of pumice fragments. Some of the pumice fragments are as much as 1 inch across. Most of the matrix of the Otowi Member consists of glassy shards and pumice fragments. No water was ~~encountered~~ found in the member in test well 8.

The outcrop tentatively assigned to the Otowi Member in the eastern part of the area in the road cut on Highway 4 consists of gray to pinkish-gray soft pumiceous ash similar to the cuttings from depths of 60 to 105 feet in test well 8.

Tshirege Member

The Tshirege Member is exposed in the walls of Mortandad Canyon and forms the mesas north and south of the canyon. Where the contact of the Tshirege Member and the underlying Otowi Member can be observed in Sandia Canyon north of Mortandad Canyon, it is an irregular erosion surface. Although the contact is concealed in Mortandad Canyon, it is probably an erosional unconformity here also.

The Tshirege Member consists of several lithologically different units, which were mapped (fig. 2) to determine the geologic structure and to determine whether the lithologic differences might affect infiltration of ~~ground water and surface~~ water.

Unit 1.--The lower part of the Tshirege Member consists of two ledge-forming layers of pumiceous tuff breccia that are generally similar in lithology, but are slightly different in color and weathering characteristics. The lower layer is here designated layer 1a (fig. 2), and the upper layer is here designated layer 1b.

Layer 1a is massive orange-weathering pumiceous tuff breccia which forms a low ledge above the alluvium at many places in Mortandad Canyon east of the western part of sec. 23, T. 19 N., R. 6 E. This basal layer of the Tshirege Member persists across much of the Pajarito Plateau. Layer 1a is composed of pink to light-salmon colored fragments of pumice ranging from 1/8 inch to 6 inches in largest dimension. Many of the pumice fragments contain tiny subhedral quartz crystals mainly about 1/16 inch across. Also present are fragments of obsidian and rhyolite. The interstices between fragments are filled with fine glassy ash. The unit is probably an explosive volcanic breccia laid down as an ash flow. The weathered outer 1 to 3 inches of layer 1a is a hard rind which protects the unweathered rock from erosion. The upper $2\frac{1}{2}$ feet of layer 1a forms a hard ledge, and the top of the layer forms a narrow flat bench at many places.

The thickness of layer 1a is varied because of the irregular erosion surface at the top of the Otowi Member on which layer 1a rests. Just west of State Highway 4 the base of layer 1a is concealed by talus, but the unit seems to be about 15 feet thick. Farther west layer 1a is thicker at most places, but its actual thickness can be determined only in the vicinity of test well 8. Here the base of layer 1a is about 60 feet below land surface, and the top--a slight notch weathered in the cliff on the north wall of the canyon--is about 10 feet above the surface. Thus, layer 1a is about 70 feet thick near test well 8. Exposures in Sandia Canyon indicate that the thickness of layer 1a varies considerably in short distances.

Layer 1b rests conformably on layer 1a and weathers to dull grayish brown, pink, and light orange. Layer 1b is a tuff breccia with a fine-grained pink ash matrix similar to layer 1a, but the pumice fragments in layer 1b are smaller, and 15 to 20 percent of the material consists of granule-sized quartz-crystal fragments and fragments of dense volcanic rock. At most places layer 1b is slightly less resistant to erosion than layer 1a and forms a rounded ledge set back from 1a (fig. 5). At some places layers 1a

Figure 5.--View of the north wall of Mortandad Canyon northwest of observation well MCO-8. Qbt_{1a}, layer 1a; Qbt_{1b}, layer 1b; Qbt_{2a}, layer 2a; Qbt_{2b}, layer 2b of the Tshirege Member of the Bandelier Tuff.

and 1b together form a nearly vertical cliff. At these places the layers can be distinquished because a soft bed of pumice at the base of layer 1b weathers to a persistent notch in the cliff. Layer 1b is fairly uniform in thickness, ranging from about 18 to 22 feet thick.

Unit 2.--Unit 2 of the Tshirege Member rests conformably on layer 1b and seems to be transitional into it. In the eastern part of the mapped area, unit 2 consists of two layers separated by an erosional unconformity. These layers are designated (fig. 2) from lowest to highest, 2a and 2b. West of test well 8 the contact between the layers could not be determined with assurance, and they were mapped together as unit 2.

Layer 2a is light-gray pumiceous tuff. The tuff consists of slightly welded pumiceous ash containing angular fragments of pumice, dense rhyolite, and latite as large as 4 inches across. Also present are fragments of quartz and sanidine crystals. The rock is similar to parts of the Otowi Member and weathers to dull gray and grayish-brown with a hard rind several inches thick at its surface. Layer 2a weathers to rounded slopes set back from unit 1. Layer 2a is about 55 feet thick in the eastern part of the area, and the thickness increases westward to 70-80 feet in the vicinity of test well 8.

Layer 2b is tan- to brown-weathering tuff composed of fragments of quartz crystals and some sanidine crystals in a matrix of fine ash. Pebble-sized fragments of pumice and rhyolite also are present. Bedding can be observed at places in this layer, and commonly the lower 6 inches consist of shaly bedded fine- to coarse-grained tuffaceous sandstone which rests on an erosional surface at the top of layer 2a. Layer 2b is resistant to erosion and forms ledges and benches above the rounded slopes of layer 2a. In the eastern part of the area the preserved part of layer 2b ranges from 5 to 30 feet thick. In the western part of the area layer 2b is about 40 feet thick and grades upward into unit 3; the contact was mapped mainly on a topographic basis near the break in slope between the bench held up by layer 2b and the rounded slope cut on unit 3. West of test well 8 layers 2a and 2b form a ~~single~~ weathering unit mapped as unit 2. Unit 2 is 110 to 120 feet thick.

Unit 3.--Unit 3 rests conformably on unit 2 and grades downward into it. Unit 3 consists mainly of light-gray, light-tan, pink, and white slightly welded pumiceous tuff breccia. The rock is composed of fine pumice fragments and glassy shards, and contains numerous layers of pebble- and cobble-sized pumice fragments and some red and gray dense rhyolite, latite(?), and obsidian fragments. Most of the unit is relatively soft and has been eroded to form soft round slopes with a hard rind several inches thick at the weathered surface. The upper 40 to 50 feet is moderately resistant to erosion and forms flat mesas and benches with steep sides north and south of Mortandad Canyon. The upper part of this interval contains abundant fragments of dense rhyolite and latite(?). Unit 3 is about 110 feet thick in the western part of the area and is the stratigraphically highest part of the Bandelier Tuff preserved in this part of the Pajarito Plateau.

Correlations

Unit 1 of the Tshirege Member in Mortandad Canyon was traced northeastward to the typical exposure of the Tshirege Member ~~(Griggs, in preparation)~~ (Griggs, 1962, p. 97) on the mesa north of Los Alamos Canyon in secs. 16 and 21, T. 19 N., R. 7 E. At this locality layer 1a is about ~~62~~ 62 feet thick, and layer 1b is about 26 feet thick. Layers 2a and 2b also are recognizable at the typical exposure, where they are 47 feet and 31 feet thick, respectively. The lower part of unit 3 is about 49 feet thick at the typical exposure of the Tshirege, and the upper part of unit 3 is not present, having been eroded from the top of the mesa.

Units 1, 2, and 3 of the Tshirege Member are present at Technical Area 49 on Frijoles Mesa about 2½ miles south of Mortandad Canyon. Layers 1a and 1b at Mortandad Canyon correlate with unit 1b of Weir and Purtymun (oral communication ~~in preparation~~) of the Tshirege at Frijoles Mesa. The subsurface unit designated by Weir and Purtymun as unit 1a of the Tshirege at Frijoles Mesa is probably equivalent to the upper part of the rocks assigned to the Otowi Member in the subsurface at test well 8 in Mortandad Canyon. Unit 2 at Mortandad Canyon is equivalent to unit 2 of Weir and Purtymun at Frijoles Mesa. The soft lower part of unit 3 at Mortandad Canyon is equivalent to unit 3 at Frijoles Mesa. The ledge-forming upper part of unit 3 at Mortandad Canyon may be equivalent to unit 4 at Frijoles Mesa, but was not mapped separately from unit 3 at Mortandad Canyon.

Alluvium

Alluvium of Recent age rests unconformably on the Bandelier Tuff in Mortandad Canyon. The alluvium consists mainly of detritus eroded from the Tshirege Member which forms the sides of the canyon. At most places west of sec. 23, T. 19 N., R. 6 E. (fig. 2), the alluvium consists of boulders, cobbles, and pebbles of tuff intermixed with sand, silt, and clay. The sand consists mainly of fine- to coarse-grained crystal fragments of quartz and sanidine. In this part of the canyon the alluvium is probably no more than ~~20 to~~ 30 feet thick and may be only a few inches to several feet thick at places.

The alluvium east of test well 8 is thicker and consists of two more or less distinguishable units. As determined from samples from shallow observation wells and access tubes drilled in the canyon (fig. 2), the upper part of the alluvium is mainly coarse-grained, pebbly, ~~argillaceous~~ clayey, crystal-fragment sand. This unit rests on brown sandy, silty clay, which constitutes a lower unit of the alluvium and rests on the Bandelier. Some of the lower part of the clay may be a soillike material weathered in place, from the upper part of the bedrock beneath the alluvium. Generally, the alluvium is thickest near the axial part of the valley and becomes thinner toward the edges, reflecting the shape of the valley which was cut in the Bandelier Tuff before the alluvium was deposited. In the vicinity of test well 8 the alluvium is about 40 feet thick. The upper 30 feet consists mainly of crystal-fragment sand, and the lower 10 feet consists of tan clay resting on layer 1a of the Tshirege Member.

The upper 20 feet of alluvium at line 6 (MCM-6A, etc., fig. 2) consists of coarse slightly ~~argillaceous~~ clayey sand, which laps onto layer 1a of the Tshirege Member near the edges of the valley. Below the coarse sand the alluvium is mainly sandy, silty clay, which rests on the Otowi Member and is about 42 feet thick at observation well 6 (MCO-6).

The upper 20 to 25 feet of alluvium at line 8 is mostly sand with a small amount of clay. At access tube MCM-8D the lower unit of brown sandy clay seems to be more than 70 feet thick and rests on the Otowi Member. Because of the difficulty in recovering samples of drill cuttings at access tubes MCM-8C and MCM-8D, the contact of the alluvium and the Otowi Member was not determined with certainty. A change in drilling rate seemed to indicate that the base of the alluvium is at a depth of about 59 feet at MCM-8C and about 71 feet at MCM-8D, but samples from these depths consist of are sandy brown clay. This material might have caved from above, but probably was in place. The upper sand unit overlaps the brown clay unit and rests on layer 1a of the Tshirege Member near the edges of the valley.

The upper sand unit at observation well 9 (MCO-9) is 20 to 25 feet thick, and the lower unit of brown sandy clay is 32 to 37 feet thick. The alluvium rests on the upper part of the Otowi Member. At access tube 10 (MCM-10), the upper sand is about 17 feet thick. The base of the brown sandy clay unit seems to be about 62 feet below the surface where gray tuff was penetrated. ~~encountered.~~ The tuff is probably in the upper part of the Otowi Member.

The thickness of the alluvium in the canyon east of access tube MCM-10 is unknown. On the basis of extrapolation of gradients and comparison with the depth of Sandia Canyon to the north, the alluvium in Mortandad Canyon east of the Los Alamos-Santa Fe County line is probably 60 to 100 feet thick in the deepest part of the valley. East of the county line the alluvium probably rests on the Otowi Member in the axial part of the valley, but thins and laps onto layer 1a of the Tshirege Member at the edges of the valley.

The alluvium in Mortandad Canyon has a complex history of deposition and erosion. Apparently the pre-alluvium canyon was cut to a depth and form similar to the unalluviated part of Sandia Canyon north of the mapped area. The lower unit of the alluvium contains much sandy clay derived from weathering of the Bandelier Tuff. The sandy clay may have been soil eroded from the surrounding area and deposited in the canyon, or the alluvium may have been weathered to a soil-like ~~character~~ material after it was deposited. The upper sand unit is largely the product of mechanical erosion, and its constituents have not been greatly weathered. The upper part of the unit has been weathered to form clayey soil zones ranging in thickness from a few inches to several feet. The stream channel has been cut through the soil into the underlying less weathered sand.

Allu~~vium~~iation is occurring at present, and small fans of coarse detritus are accumulating at the bottom of steep slopes and at the mouths of some tributary canyons. Thin talus with intermixed sandy soil occurs on the south wall of the canyon, especially between lines 3 and 6. The talus probably creeps slowly toward the canyon bottom and contributes alluvial material to the intermittent stream. The alluvium in the upper part of the canyon above test well 8 is being eroded and redeposited a short distance below test well 8, where survey stakes have been buried by coarse crystal-fragment sand several inches thick. The alluvium in the lower part of the canyon below the Los Alamos-Santa Fe County line is being eroded slightly and some of the arroyos are entrenched 10 to 15 feet below the gently sloping upper surface of the alluvial fill.

Water was ~~encountered~~ found in the alluvium during drilling of some of the observation wells and access tubes. The water ~~appeared~~ seemed to be perched on the Bandelier Tuff. The occurrence of water in the alluvium is discussed in the later sections of this paper.

Geologic structure

The rocks of the Tshirege Member of the Bandelier Tuff dip gently eastward in the vicinity of Mortandad Canyon, as shown by the structure contours on figure 2. The contour datum is the top of layer 1a, which is the only stratigraphic horizon that is both sharply defined and persistent in the present area. The structure contours are lines connecting points of equal altitude at the top of layer 1a. In the western part of the area where layer 1a is not exposed, the positions of the structure contours on the top of layer 1a were determined on the basis of the combined measured thickness of unit 2 and layer 1b. The eastward dip of the Tshirege Member probably is mainly initial dip as the result of thinning of individual units away from their volcanic sources in the Valle Grande region west of the Pajarito Plateau. However, the rocks have been warped gently and jointed since they were laid down.

The structure of the underlying Otowi Member is not exactly the same as that of the Tshirege Member, as indicated by the eastward-thinning of the Otowi, which is 385 feet thick at test well 8, but about half as thick at most places on the eastern part of the Pajarito Plateau. Well data from Technical Area 49 on Frijoles Mesa also indicate that the base of the Bandelier Tuff and the base of the Puye Conglomerate are structurally lower in the central part of the plateau than they are at the eastern edge, suggesting that the eastern part of the plateau was tilted slightly westward and the Otowi Member was partly eroded prior to the deposition of the Tshirege Member. At places south of White Rock unit 1a dips gently west, indicating that further slight deformation occurred after the deposition of the Tshirege Member.

Joints in the rocks of the Tshirege Member were examined on the ground and interpreted from aerial photographs. The joints were examined because of their possible influence on infiltration of surface water. The joints divide the rocks of the Tshirege Member into multitudinous polygonal blocks, many of which are prismatic or columnar. The spacing of joints is irregular; ~~and~~ at many places individual joints intersect or are only a few inches or a few feet apart, whereas at other places the joints are several yards apart. The average density seems to be about 1 joint per square yard. The openings along joints range from hairline cracks to fissures several inches wide. Many of the fissures have been filled with sediment or with ~~autochthonous~~ clay derived from the weathering of the walls of the fissures. At many places the openings are not filled completely.

Many of the joints observed in the Mortandad Canyon area can be classified as master joints. As used by Kelley and Clinton (1960, p. 16), the term "master joint" signifies those joints ~~which~~ that are numerically predominant and most persistent in length and pass through several groups of beds. Most of the master joints observed are vertical, or dip more than 85°, and are generally nearly perpendicular to the layering of the Tshirege Member. The master joints can be traced vertically across two or more units of the Tshirege and, in many ~~cases~~ places, across all ~~of~~ the mapped units. The overall trends of individual master joints are relatively straight, but most joints are curved slightly along part or all of their length, and some of the shorter joints have pronounced local curvature. Other joints dipping at angles ranging from about 40 to 70 degrees are especially common in unit 2a, but they are present also in other units. These joints generally are not as persistent as the master joints.

The orientations of some of the master joints are shown on figure 6a. Each ray shown on the diagram represents many joints

Figure 6a.--Orientations of some of the master joints in the Tshirege Member of the Bandelier Tuff. Sets of similarly oriented joints are bracketed. Each ray represents several joints.

which form sets of nearly parallel fractures. The number of measurements of joint orientations is not sufficient to establish the ~~nature of the~~ fracture pattern with certainty. However, the data available seem to indicate a grouping of several sets of nearly parallel joints as shown by brackets in figure 6a. There is a difference of about 60 degrees in the orientation of several of these sets, which suggests that some of the sets are conjugate tension joints.

Ideally, the uniform shrinkage of a homogeneous medium produces sets of joints delineating nearly hexagonal prisms (fig. 6b),

Figure 6b.--Idealized fracture pattern caused by uniform shrinkage of a homogeneous medium. Arrows indicate directions of tensional stress; sides of hexagon represent tension joints.

and this phenomenon is well known in volcanic flow rocks, particularly basalt~~s~~. However, similar tensional stresses might also produce conjugate sets of joints intersecting at angles of about 60 degrees, as shown on figure 6c, and the conjugate sets of

Figure 6c.--Pattern of conjugate sets of joints intersecting at 60 degrees. Arrows indicate some of the local directions of tensional stress.

fractures would not necessarily produce hexagonal prisms. Thus it seems probable, on the basis of the data available, that many of the master joints in the Tshirege Member were produced by tensional stresses caused by shrinkage during cooling of the rocks.

If the joints were caused by shrinkage, they probably are open slightly at many places and might provide channels for infiltration of surface water. Open joints are common in the Tshirege Member in the large-diameter holes drilled on the mesa top at Technical Area 49 ~~(Weir and Purtymun, in preparation)~~. In Mortandad Canyon, on the topographic bench on unit 2 north of Ten Site, melt water from snow was observed to flow in small depressions weathered along joints and to infiltrate completely in less than 100 feet.

No data are available concerning the water-transmission characteristics of joints in the Tshirege Member beneath the alluvium in the canyon. Probably most of these joints are partly filled with alluvial material or with clay derived from weathering of the rock on the sides of the fractures. This may effectively seal the upper parts of most joints in the valley and inhibit infiltration of ground water from the alluvium. This conclusion is not substantiated by direct observation at Mortandad Canyon, but conditions at places on the mesas may be analogous in certain respects. Soil-moisture measurements indicate that the thin cover of clayey soil on the mesas inhibits infiltration of precipitation (Abrahams, Weir, and Purtymun, 1961). The weathered upper parts of joints are largely sealed by ~~autochthonous~~ clay where the Bandelier is overlain by soil at Technical Area 49, ~~(Weir and Purtymun, in preparation).~~

If the joints in the Tshirege Member are the result of shrinkage during cooling, they may not be connected directly with joints in the Otowi Member because these units cooled separately. However, it would be reasonable to expect some fortuitous juxtaposition of joints in the two members that might allow percolation downward to the Puye Conglomerate if water is able to infiltrate at the surface.

Hydrology

The surface water and two bodies of ground water are of concern in this study. The two ground-water bodies are: the water of the main aquifer, which is in the Puye Conglomerate more than 985 feet beneath the floor of the canyon, and the water perched in the alluvium at shallow depth in Mortandad Canyon. No water was ~~encountered~~ found between the base of the alluvium and the top of the main aquifer during the drilling of the deep test hole.

The source or sources of recharge of the main aquifer in the Los Alamos area are not known with certainty. The altitude of the piezometric surface of the main aquifer is higher in the western part of the Pajarito Plateau than in the eastern part. (See fig. 12.) This suggests that the major recharge areas are in the western part of the plateau or in the Sierra de los Valles. However, if some of the areas of recharge for the main aquifer are in Mortandad Canyon and other canyons on the plateau, contaminants from wastes discharged in the canyons might be carried directly to this aquifer which is the source of the water supply for Los Alamos.

The source of the water in the alluvium in Mortandad Canyon is precipitation in the upper part of the canyon and in its tributaries. After the water filters into the alluvium, its possible routes of movement and points of discharge are: 1) lateral movement through the alluvium to the mouth of Mortandad Canyon where the water might discharge from springs or seeps into the Rio Grande; 2) vertical movement from the alluvium through the underlying Bandelier Tuff and Puye Conglomerate to the main body of ground water in the lower part of the Puye and the Tesuque Formation; 3) return to the atmosphere from the alluvium through ~~because of capillary action, evaporation, and transpiration from plants~~ evapotranspiration; or 4) a combination of ~~two or more~~ routes. The movements of liquid waste discharged into the canyon probably would be similar, if not identical, to the movements of the naturally occurring surface water and ground water.

A primary reason for constructing observation wells and access tubes in Mortandad Canyon was to determine, if possible, whether the water in the alluvium filters into the Bandelier Tuff beneath the alluvium or moves eastward toward the Rio Grande.

Construction of wells and access tubes

Thirty-three test holes, each less than 100 feet deep, and a test hole 1,065 feet deep were drilled and finished in Effluent and Mortandad Canyons in October and November 1960. The deep hole and 10 of the shallow holes were cased as wells for collecting water samples and making water-level measurements. The other 23 shallow holes were cased to seal out water and were used as access tubes to accommodate the neutron-neutron scattering probe, which was used to determine the moisture content of the alluvium and bedrock.

Shallow wells and access tubes

Nine shallow observation wells were constructed to study the water in the alluvium in Mortandad Canyon. The wells are designated as Mortandad Canyon observation wells (MCO-1 through MCO-9) and were numbered from west to east (fig. 2). Moisture-measurement access tubes were constructed in seven lines across the canyon. Each line includes one observation well and two or more access tubes. Each access tube is designated by a number, which corresponds with the number of the observation well in each line, and by a letter. The tube at the south end of each line is denoted by the letter "A" (MCM-1A, MCM-2A, etc.). Lines 1 and 2 are in Effluent Canyon, and lines 3 to 6 and 8 are in Mortandad Canyon. MCO-7 and MCO-9 are observation wells with no accompanying access tubes, and MCM-10 is a single access tube. Test well 8A near line 5 is utilized as a shallow observation well, but it was not constructed in the same manner as the other shallow wells.

The holes for the observation wells and access tubes were drilled by a truck-mounted power auger, where possible, and by a portable power auger in places inaccessible to the truck. The diameters of the augers for the truck-mounted and portable rigs were slightly less than 4 and 3 inches, respectively. Samples were obtained during augering of the holes, but there was no assurance that samples designated as being from a specific depth were representative of that depth because the cuttings were mixed by the auger and because the sides of the holes caved. It was impossible to obtain cores with this equipment because material that caved from the sides of the hole could not be cleaned out completely.

Two observation wells ranging in depth from 8 to $10\frac{1}{2}$ feet were constructed in Effluent Canyon, and 8 observation wells ranging in depth from $17\frac{1}{2}$ to 80 feet were constructed in Mortandad Canyon. Wells MCO-2, 3, and 4 were drilled with the portable power auger and cased with 2-inch plastic pipe (table 1). The other wells were drilled with the truck-mounted auger and cased with 3-inch plastic pipe. Three-inch-diameter pipe was used where possible to facilitate the collection of water samples and to make possible the operation of recording gages ~~float-type water-level recorders~~. The plastic casing was perforated with heated screw drivers (1/8-inch wide and $\frac{1}{4}$-inch long perforations) or a heated ice pick (1/8-inch diameter). The perforations were in vertical rows about 1 inch apart with five rows around the pipe. The bottom of the pipe (except MCO-3) was left open.

Table 1.--Record of shallow observation wells in Effluent and Mortandad Canyons, Los Alamos County, N. Mex.

Well No.	Casing diameter (inches)	Depth drilled (feet)	Depth sounded (feet) April 1961	Length of casing below land surface (feet)	Length of casing perforated (feet) 1/	Altitude of land surface (feet)	Height of measuring point 2/ (feet) above land surface	Depth to water below land surface (November 1960) (feet)
MCO-1	3	8	7.9	1.2	1	7153.3	2.8	1
MCO-2	2	10.5	6.1	9.9	13	7133.5	3.1	1
MCO-3	2	17.5	12.7	12.7	10	7046.2	1.5	8
MCO-4	2	24	21.9	23.5	15	6900.4	.5	16.90
MCO-5	3	47	32.6	38.5	15	6876.7	1.5	24.60
MCO-6	3	82	68.2	70.7	35	6848.9	7.0	38.11
MCO-7	3	77	64.6	68.5	30	6827.6	1.5	39.66
MCO-8	3	92	80.2	83.4	20	6797.3	1.6	61.51
MCO-9	3	67	55.7	55.5	50	6749.8	1.5	Dry
TW-8A	24	40	27.9	30	3/	6874.7	.0	26.8

1/ Measured from the bottom of the casing.

2/ Top of casing.

3/ Corrugated metal pipe, 24-inch diameter, bottom open.

The annular space between the wall of the hole and the pipe was packed with soil from the surface to a depth of 2 or 3 feet. Below this the annular space is open. The annular space from the bottom to within 3 feet of the land surface in MCO-4 was filled with sand, and the upper 3 feet was packed with soil. After the casings were set, the wells were bailed with a 1-gallon bailer to clean and develop them.

Test well 8A is cased with a 24-inch-diameter corrugated metal pipe to a depth of 30 feet and is utilized as a shallow observation well. There are no slots or perforations in the casing, but the bottom is open.

Four moisture-measurement access tubes ranging in depth from 1 to 12 feet were constructed in Effluent Canyon, and 19 access tubes ranging in depth from 10 to 86 feet were constructed in Mortandad Canyon (table 2). The holes in lines 3 and 4 were drilled with the portable auger, and the others were drilled with the truck-mounted auger. The access tubes are cased with 2-inch-diameter plastic pipe to accommodate the moisture and density probes. The bottom of each pipe was sealed with a plastic cap to keep water out of the pipe.

The annular spaces between the pipe and wall of the holes were filled with dry sandy soil or tuff which did not contain clods or pebbles. A narrow strip of wood 20 feet long was used to tamp the fill into the annular space. The lower parts of the pipes in access tubes MCM-8C and MCM-8D were set in mud slurry, but only the top 10 feet of the annular space was backfilled.

Table 2.--Record of access tubes in Effluent and

Mortandad Canyons, Los Alamos County, N. Mex.

	Length of casing below land surface (feet)	Altitude of land surface (feet)	Height of measuring point 1/ above land surface (feet)
MCM-1A	11.7	7,155.9	1.7
-1B	10.5	7,154.7	2.2
-2A	11.0	7,138.6	.7
-2B	1.0	7,133.7	2.9
-3A	13.0	7,048.8	2.2
-3B	10.0	7,048.3	2.2
-4A	9.0	6,900.9	.7
-4B	23.5	6,900.0	.0
-5A	25.0	6,881.4	1.7
-5B	30.0	6,879.0	1.7
-5C	37.0	6,877.6	2.2
-6A	17.8	6,852.6	1.2
-6B	51.8	6,851.2	1.2
-6C	56.8	6,851.0	1.2
-6D	34.9	6,850.0	1.2
-6E	21.0	6,850.6	1.2
-8A	20.0	6,807.1	1.2
-8B	30.0	6,797.2	1.2
-8C	66.0	6,797.3	1.2
-8D	86.3	6,796.3	1.2
-8E	52.6	6,796.9	1.2
-8F	23.1	6,799.2	1.2
-10	67.2	6,730.9	1.2

1/ Top of casing.

Deep test well

A deep test ~~hole~~ well was drilled in Mortandad Canyon near the middle of sec. 23, T. 19 N., R. 6 E. The ~~hole~~ well was bottomed at a depth of 1,065 feet in the main aquifer of the Los Alamos area. This ~~hole~~ well is designated as test well 8 (TW-8 on fig. 2). The ~~hole~~ well was drilled by the cable-tool method. Drilling began on November 8, and the well was completed December 15, 1960. Drilling time was recorded and rock cuttings were collected at depth intervals of 5 feet. The drilling-rate log, a description of the cuttings, and details of well construction are shown on figure 4. A hole 18 to 20 inches in diameter was drilled to a depth of 85 feet. From 85 feet to the total depth of 1,065 feet, a hole 13 5/8 inches in diameter was drilled.

An unperforated steel casing, 20 inches in diameter and 43.5 feet long, was driven to a depth of 42 feet ~~below land surface~~ to seal out water in the alluvium. A 14-inch-diameter steel casing, 64 feet long, was suspended inside the 20-inch casing. Cement was poured around the 14-inch casing to fill the annular space from a depth of 62 feet to the land surface (fig. 4). An 8-inch casing, 1,067 feet 11 inches long, was suspended inside the 14-inch casing in such a manner that the 8-inch casing does not rest on the bottom of the hole. Slots were cut with an acetylene torch in the lower 112 feet of the 8-inch casing. The slots are 6 inches long, 1/8 inch wide, and are spaced 90 degrees apart horizontally. The vertical spacing is 6 inches between the horizontal rows of slots, and the slots of each row are staggered 45 degrees horizontally, with respect to the slots in the next row above and below. The well was partly developed by bailing for 1 hour on December 15; it was developed additionally ~~development occurred~~ during a 2-hour bailing test on December 16, 1960.

If surface water or shallow ground water should begin to leak down around the 20-inch and 14-inch surface casings, it may be possible to seal the upper 465 feet of the well by pouring grout into the annular space between the 8-inch casing and the borehole. A packer made of machinery belting is attached to the outside of the 8-inch casing at a depth of 465 feet to provide a bridge for the grout. Access to the annular space above this bridge is provided by a 3-inch-diameter pipe at the well head (fig. 4).

The first attempt to drill a deep test ~~hole~~ well was abandoned at a depth of 40 feet, because a drill bit and holding wrench were lost in the hole. This ~~hole~~ well, designated test well 8A (TW-8A), is about 50 feet east of TW-8 and is used as a shallow observation well.

Collection of hydrologic data

The shallow observation wells were the principal sources of data on the perched water in the alluvium. Periodic measurements of the depth to water were made with a steel tape from late March to July 1961. ~~to determine changes of water levels in the alluvium.~~ ~~Water-level~~ record~~ers~~ing gages were installed on several wells. Samples of water were collected for radiochemical and chemical analysis.

The moisture-measurement access tubes were used mainly to determine the moisture content of the alluvium above the perched water table, but the moisture measurements also yielded data on the depth to the water table.

Two electronic instruments containing sources of radioactive materials were used in the access tubes to determine the moisture content and the density of the undisturbed materials outside the plastic pipe. Each instrument is a probe about 1-9/16 inches in diameter and about 14 inches long and is connected by an insulated cable to a portable power supply and scaler. The cable is marked in feet, and the probe can be lowered by the cable to any depth desired in the access tube. The moisture content in percentage by volume, or the density in pounds per cubic foot, of the material surrounding the access tube is determined directly by comparing readings on the scaler with empirically determined charts and graphs. The minimum sphere of influence of the probes is about 6 inches in diameter.

The radioactive source in the moisture probe emits fast neutrons, which are slowed by collisions with free hydrogen atoms in the surrounding materials. Some of the slow neutrons are deflected back to a detecting tube in the probe and counted electronically, thus providing a means of determining the percentage by volume of moisture in a sphere around the probe. The radioactive source in the density probe emits gamma-rays, which collide with orbital electrons of atoms comp~~rising~~osing the material surrounding the plastic pipe. Because gamma-rays are scattered and absorbed in direct proportion to the number of electrons per unit volume, the number of gamma-rays that will be deflected back to the detecting tube is inversely proportional to the density of the surrounding material. This provides a means of determining the density of the material around the probe.

A 2-inch I.D. (inside diameter) plastic pipe was used to case the moisture-measurement access tubes instead of the 1 5/8-inch I D steel tubing recommended by the manufacturer of the probes. Fabrication under field conditions of numerous lengths of the tight-fitting steel tubes was found to be impractical. The greater distance between the probe and the undisturbed material, ~~that~~ which resulted from using the larger-diameter pipe, probably caused some small error in measuring the moisture content. The moisture content determined by using the 2-inch plastic pipe ~~appears~~ seems to be ~~about~~ from 1 to 2 percent low by volume in the intermediate moisture range. The instrument was calibrated by comparing actual moisture readings with the laboratory-determined moisture content of cores. Moisture measurements made in observation well MCO-8, which is cased with 3-inch I D plastic pipe, are ~~believed to be~~ probably correct within ~~about~~ 2 or 3 percent by volume. It was necessary also to recalibrate the density probe in the field before it could be used with the plastic pipe.

Data obtained from the shallow observation wells and access tubes were used to draw profiles of the alluvium in Mortandad Canyon. Profiles along each line of holes across the canyon are shown on figure 7, and longitudinal profiles between line 4 and

Figure 7.--Profiles across Mortandad Canyon showing water levels and moisture content of the alluvium and the Tshirege and Otowi Members of the Bandelier Tuff.

access tube MCM-8D are shown on figure 8. The top of the zone of

Figure 8.--Longitudinal profiles showing base and top of the alluvium and water levels in the alluvium in Mortandad Canyon between MCO-4 and MCM-8D. (Line of profiles shown on fig. 2.)

saturation of the alluvium and the moisture content of the zone of aeration of the alluvium are illustrated on these profiles.

The base of the alluvium in several holes was determined with certainty by microscopic examination of auger samples. Where auger samples did not provide conclusive data, the base of the alluvium was interpreted from driller's logs, changes in the moisture content as determined with the moisture probe, and differences in the density of the materials as determined with the density probe. The water in the alluvium is perched on the tuff at all localities where the contact of the alluvium and underlying Bandelier Tuff was determined with certainty from auger samples, and there is a significant difference between the moisture content of the saturated alluvium and the moisture content of the underlying unsaturated tuff. The position of the sharp decrease in moisture content was used in defining the probable alluvium-tuff contact at places where the contact could not be determined conclusively from the driller's log and auger samples. Generally, the density of the alluvium is 100 pounds per cubic foot, or slightly more, whereas the density of the tuff is about 90 pounds (plus or minus several pounds). The position of the change in density was used as supplemental information in determining the alluvium-tuff contact.

Water in the alluvium

Source of recharge

The source of recharge of the ground-water body in the alluvium in Mortandad Canyon is the precipitation within the drainage area of the canyon. The canyon does not extend westward to the Sierra de los Valles, where the annual precipitation ~~at higher altitudes~~ is as much as ~~30 to~~ 35 inches and the drainage area of the main canyon west of the Los Alamos-Santa Fe County line is only about 2 square miles. The head of Mortandad Canyon is on a relatively low part of the Pajarito Plateau at an altitude of about 7,400 feet, where the average annual precipitation is only 17 or 18 inches. Thus, the amount of recharge water available for the alluvium in Mortandad Canyon is relatively small compared to that available for the alluvium in other canyons on the Pajarito Plateau.

Approximately one-fourth of the precipitation in the vicinity of Mortandad Canyon ~~occurs~~ is in the winter ~~months~~. During the present investigation, from October 1960 to June 1961, most of the precipitation ~~occurred~~ was in October, December, March, and April (fig. 9). West of line 5 snow remained on the ground ~~in the~~

Figure 9.--Temperature and precipitation at Los Alamos, N. Mex. from October 1960 through June 1961.

in the canyon, especially along the south wall, from late November to early April. Snow depths of 1 to 2 feet were common during this period, although sublimation and diurnal melting reduced the snowpack between periods of precipitation. West of line 5 the shade provided by the canyon walls, deciduous and evergreen trees and shrubs was ~~important~~ a major factor in retaining the snow. At most places in the broader part of the canyon east of line 5 the snow melted or sublimated within a few days after each snowfall.

Figure 9 shows the daily and monthly precipitation and daily high and low temperatures during the period of study. The measurements were made at the Administration Building of Los Alamos Scientific Laboratory about half a mile northwest of upper Mortandad Canyon. ~~It is estimated that~~ The daily low temperatures in the upper part of the canyon are estimated to be 5 to 7 degrees lower than those of the plateau, whereas the daily high temperatures in the broader lower reach of the canyon often are higher than on the plateau.

Temperatures during parts of 15 days in January, 20 days in February, and 23 days in March were high enough for some snow to melt at the less shaded places in the upper reach of the canyon. The length of daily melting time increased with the season, and after about April 20 melting was more or less continuous. The stream in Mortandad Canyon began to flow past line 3 in the upper reach of the canyon in March, and the downstream end of the flow advanced eastward to a point about 100 yards east of TW-8A on April 17 or 18. After this date the eastern end of the stream receded rapidly upstream, because the snowpack in the upper part of the canyon was depleted.

This sequence of advance and retreat of the stream front reflects the melting of accumulated snow; and ~~also~~ additional precipitation from the middle of March until about the middle of April, after which there was no significant precipitation until late June. The stream front retreated in April and May as the snow pack was depleted and as moisture drained from the soil and alluvium in the upper part of the canyon. By May 12 the front of the stream had retreated west of the confluence of Mortandad and Effluent Canyons. The estimated volumes of streamflow are discussed in a latter section. Records indicate that the range in temperature and amount of precipitation from October 1960 through June 1961 were about average.

Most of the precipitation on the Pajarito Plateau ~~falls~~ is during summer thundershowers, commonly during the afternoon or early evening. It often occurs as cloudbursts with several inches of rain falling in a few hours on a small part of the plateau. The highest average monthly precipitation is in August and is slightly less than 4 inches. High measurements for August during the last 10 years were 11.18 in 1952, 7.89 in 1957, and 7.24 in 1959. After June 27, as a result of summer rains, the streamflow in 1961 (after the period of study for this report) was nearly continuous in the upper part of the canyon above line 3, and the front of the stream advanced and retreated several times between lines 3 and 4.

No streamflow was observed in the lower part of Mortandad Canyon below line 6 at any time during the study. The volume of porous and permeable alluvium in the lower part of the canyon was sufficient to accommodate the infiltrating streamflow during the spring of 1961. Presumably there is intermittent streamflow in stretches of the lower part of the canyon during heavy summer rains, but the discontinuous nature of the stream channels indicates that this water infiltrates rapidly and does not flow far at the surface.

Infiltration

The snowpack in the upper part of Mortandad Canyon provided most of the recharge water for the alluvium in the canyon during the spring of 1961. The thin alluvium at places in the upper part of the canyon above line 4 probably became saturated up to the level of the streambed by early March because of infiltration of water derived locally from diurnal melting in January, February, and March. The alluvium at lines 3 and 4 remained saturated up to the level of the streambed during most of April (hydrographs, fig. 7).

~~It was difficult to determine during the investigation whether~~ ~~most of~~ The winter melt water in the upper part of the canyon may have infiltrated directly downward through the thin soil ~~which is~~ at the top of the alluvium, or it may have trickled into the stream channel and then infiltrated the alluvium. At the time of the April 11-14 moisture measurements at lines 3, 4, and 5 (fig. 7), the moisture content within the capillary fringe above the zone of saturation was 20 to 30 percent by volume. The moisture content above the capillary fringe was 10 to 20 percent by volume, and the moisture content of the upper 1 foot of soil was as much as 30 percent at some places, particularly on the shaded south side of the canyon floor, which remained frozen during the colder months. Considering the relatively low moisture content of the upper part of the capillary fringe, it appears that the moisture absorbed and retained by the clay in the upper part of the soil had a perching effect, and much of the melt water moved laterally at the surface to the stream channel, this being the path of least resistance.

Th~~is~~e infiltrating water probably saturated or partly saturated much of the thin alluvium above line 4 by the time that general melting began in March. Streamflow began in March, because the thin alluvium above line 4 was unable to absorb and transmit all the snowmelt water. The front of the ~~surface~~ stream advanced eastward in March as the stream saturated, or partly saturated, the alluvium immediately subjacent to the streambed, causing a temporary perching effect where the surface flow was large enough to exceed the rate of infiltration. Infiltration occurred at the front of the ~~surface~~ stream and in the channel throughout the reach upstream from the front. However, the front of the stream advanced eastward more rapidly than did the front of the zone of complete saturation in the alluvium. This was observed at TW-8A where the front of the stream passed the well on or about April 1, but the water level in the well indicated that the alluvium was not saturated to the level of the stream channel until April 13 or 14.

The rate of lateral movement through the alluvium in the reach upstream from the front was sufficiently slow to cause a small mound of ground water to form in the alluvium directly beneath and parallel to the channel. The mound existed from the point upstream where the alluvium was saturated to the level of the stream channel to some point west of the front of the surface stream. The sides of the mound sloped away from the channel. This is shown by the slope of the water table away from the observation wells toward the estimated positions of the water table (sharp increases in moisture content) at the access tubes in lines 3, 4, and 5 during the April 11-14 measurements (fig. 7). The eastern front of the mound also sloped steeply near the front of the ~~surface~~ stream (fig. 8).

A streamflow of about 250 gpm was measured near line 3 on March 27, 1961 when the flow in the channel was near maximum for the season and the front of the stream was progressing downstream between lines 4 and 5. The ~~rate of~~ flow on March 27 diminished eastward to a point a short distance upstream from line 5, where, because of infiltration into the alluvium, it decreased from ~~an~~ about ~~estimated~~ 75 gpm to no flow within a reach of about 15 yards. The front of the ~~surface~~ stream progressed downstream until April 17 or 18, when it reached a point about 100 yards east of TW-8A. Here the volume of alluvium was great enough to absorb all ~~of~~ the surface water until the snowpack in the upper part of the canyon was depleted. The flow near line 4 on April 27, 1961, when the front was receding upstream, was about 40 gpm.

No surface flow was observed in the broad lower part of Mortandad Canyon below line 6. Much of the snow in this part of the canyon evaporated or sublimated during the period of study. Thin clayey soil at the surface may have inhibited filtration of the melt water to some extent, because the clay absorbs water and swells slightly to form a less pervious soil. The increase in moisture content of the soil and upper part of the alluvium at lines 6 and 8 and MCM-10 indicates that some water infiltrated during the melting of winter snows and heavy spring snows. The maximum depth of infiltration of this water was 6 or 7 feet (tube MCM-6D, fig. 10). Most of the water ~~this~~ infiltrat~~ion~~ed ~~occurred~~

Figure 10.--Moisture content at five access tubes in Mortandad Canyon.

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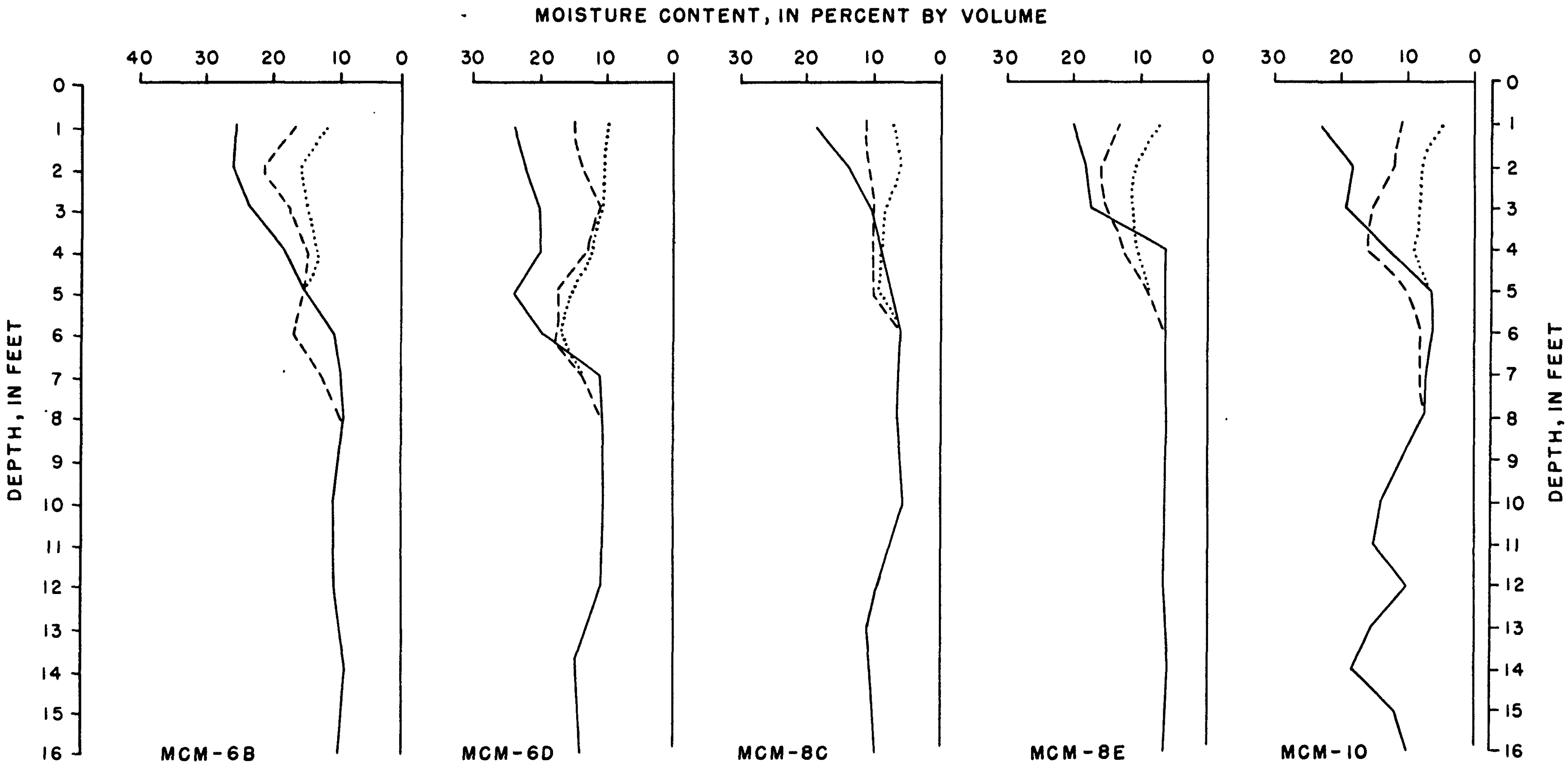
during the relatively cool months of March and early April, when there was alternate freezing and thawing in the canyon and when the evaporation was low.

Measurements in May and June show that some of the water in the top several feet of soil and alluvium drained downward toward the 8-foot depth. Below the 8-foot level there are practically no changes in the moisture curves that can be attributed to downward movement of water that infiltrated near the access tubes, and the June decline in moisture content above the 8-foot level probably is due mainly to evapotranspiration.



Curves showing moisture content.

April 11-14, 1961 | May 23-25, 1961 | June 14-16, 1961

Where the May and June curves coincide with the April, curve only the solid line is shown. Where the May and June curves coincide, only the dashed line is shown.

Figure 10.--Moisture content at five access tubes in Mortandad Canyon.

The moisture content below a depth of about 6 to 8 feet, and above the water table, is 8 to 10 percent at access tube MCM-6B and $6\frac{1}{2}$ percent at MCM-6C (fig. 7). The ~~fact that there was no~~ lack of increase in the moisture content between depths of about 6 and 20 feet suggests that the low content is the result of a long-term redistribution of moisture rather than annual wetting and draining in the upper sand unit of the alluvium. Similarly, the low moisture content of $6\frac{1}{2}$ percent in the upper part of the alluvium around MCM-8C and -8D suggests a long-term period of redistribution. However, the relatively high moisture content at the depth interval of 25 to 35 feet at observation well MCO-8 (fig. 7) is near the top of the lower silty clay unit of the alluvium. This water probably is local surface flow that infiltrated the streambed and percolated down through the upper sand unit to the sandy clay unit. There ~~appears~~ seems to have been only a limited amount of lateral movement along the top of the perching sandy clay unit, so that the quantity of water involved is relatively small. The 18 or 19 percent moisture found in the upper 20 to 25 feet around access tubes MCM-8B and -8C may be the result of some water moving laterally from the vicinity of the channel.

The stream channels in the part of the canyon below line 6 are discontinuous, and contain ~~there is~~ considerable evidence of abandonment of channels and lateral migration of intermittent streams. This probably is related to the high infiltration capacity of the highly porous and permeable upper sand unit of the alluvium. ~~It would appear that,~~ even during periods of heavy precipitation and runoff, the surface flow in the channels probably infiltrates into the upper sand unit in short distances, so that ~~there is no through~~ drainage in the lower part of the canyon is discontinuous. The intermittent stream symbol shown (fig. 2) in the part of the canyon east of the Los Alamos-Santa Fe County line indicates the ~~topographically~~ lowest part of the canyon. However, there is no single integrated system of channels in much of this part of the canyon. No heavy storm flow is known to have occurred during the present investigation, and the low moisture content at line 8 and MCM-10 indicates that this was not an important source of recharge during the period of the present investigation. Infiltration from this source is most likely to happen ~~occur~~ during summer thunderstorms.

During heavy precipitation, small amounts of water undoubtedly enter the alluvium in the lower part of the canyon through the coarse alluvial fans at the mouths of side canyons. However, data from access tubes MCM-6A, -6E, -8A, and -8E near the walls of the canyon bottom in the Bandelier Tuff at relatively shallow depths beneath the floor of the canyon ~~and measurements in those holes~~ indicated that the moisture content of the tuff generally is less than 10 percent and commonly less than 5 percent. This low range of moisture content is common also in tuff beneath the soil on the mesas and probably indicates that little, if any, moisture percolates down through the soil into the tuff.

The moisture-measurement curves illustrated on figure 10 indicate slight differences in infiltration at different places in the canyon. Mortandad Canyon west of line 6 is narrower and more heavily forested than at line 8 and MCM-10. Sublimation and evaporation of the snow is greatly reduced around MCM-6B and -6D, because the area is in shade a large part of the day; therefore, more of the snowmelt is available to percolate into the ground. At line 8 where the canyon is broad and flat and contains few trees, the daytime temperature near the surface of the alluvium is greater than near line 6, and much of the water from precipitation and runoff evaporates instead of infiltrating. Tube MCM-10 is in a depression which is an abandoned stretch of stream channel, and water ~~which~~ that accumulates in this depression infiltrates the soil rather than draining away; thus the moisture content of the soil and alluvium is higher here than at line 8.

In summary, the data obtained during the investigation indicate that most of the water recharged to the alluvium in Mortandad Canyon in the spring of 1961 was derived from the snowpack in the part of the canyon above line 4. The alluvium in that part of the canyon was saturated rapidly by infiltration of melt water in the stream channel. As the alluvium was saturated, the front of the ~~surface~~ stream advanced to a point between lines 5 and 6, where the alluvium widens and thickens. The volume of unsaturated alluvium was sufficiently large to absorb the surface flow of about 250 gpm until the snowpack was depleted. The stream front retreated as the ~~rate of~~ flow decreased. Some water infiltrated in the canyon below line 6 during the period of study, but probably only the water that infiltrated in the stream channel reached the water table. The rise of the water table below line 6 is the result of underflow of water that infiltrated the alluvium above line 6.

Movement of water through the alluvium

The movement of water through the alluvium was interpreted from periodic measurements of the changes in water levels in the observation wells and the changes in moisture content in the access tubes. The records of changes are shown by the hydrographs and moisture-content curves on figure 7 and water levels on figure 8. Details of water-level changes at observation wells are illustrated on figure 11.

Figure 11.--Hydrographs showing changes in water levels in observation wells in Mortandad Canyon, October and November 1960, and March through June 1961.

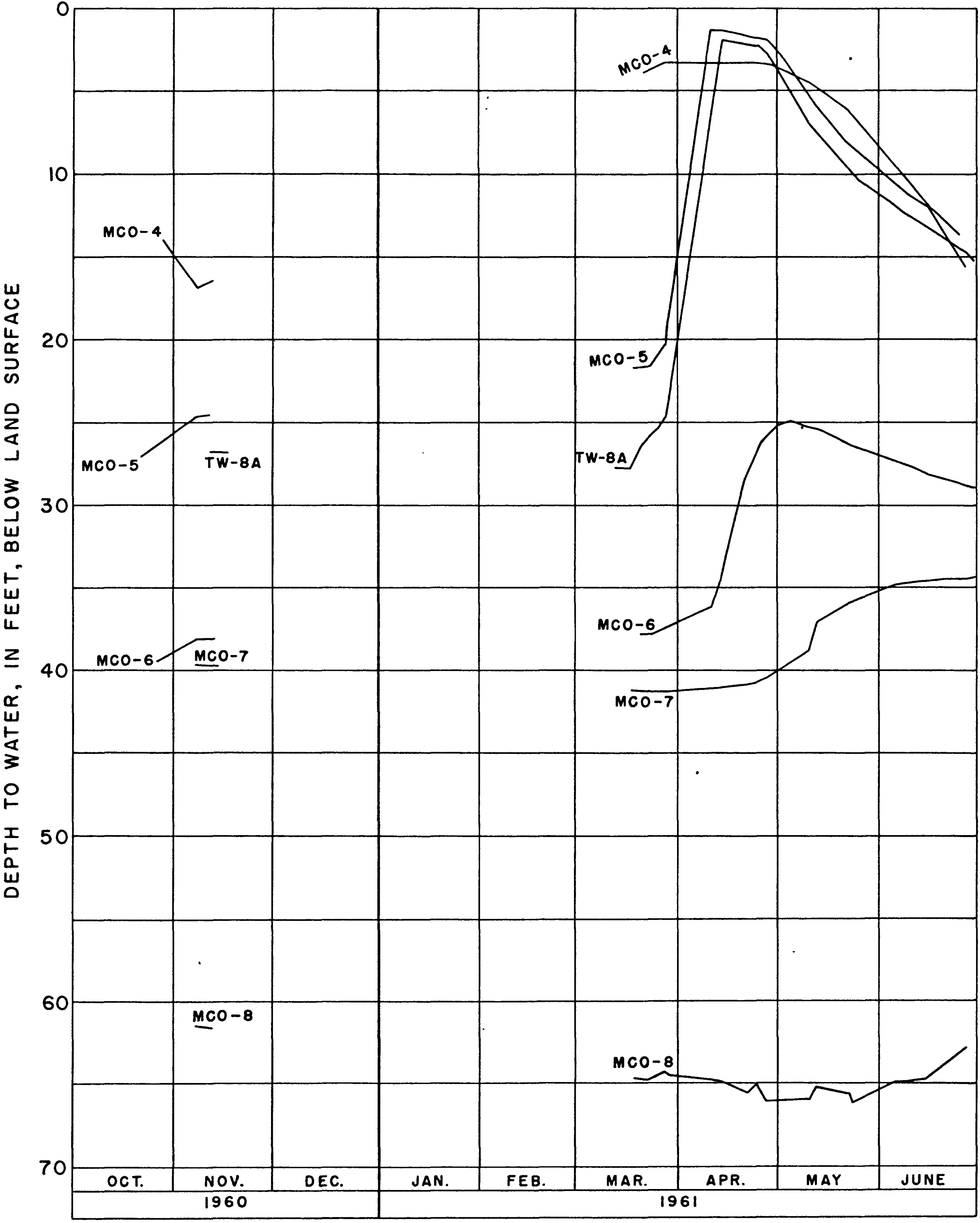


Figure 11.-- Hydrographs showing changes in water levels in observation wells in Mortandad Canyon, October and November 1960, and March through June 1961.

In the present study the changes in moisture content with time are important for determining the vertical and lateral movement of water. The position of the water table at a given time in most of the profiles across Mortandad Canyon (fig. 7) can be determined approximately by projecting lines from a circled position on the hydrograph to the moisture-content curves for the same date. For example, a line projected horizontally from the May 23-25 position of the water level at MCO-6 intersects the moisture curves at approximately the May 23-25 position of the top of the zone of maximum moisture content at MCM-6B, -6C, and -6D. The normal procedure in determining moisture content was to make a reading at each 1-foot interval of depth. Readings with the moisture probe in some access tubes were made at 3-inch intervals near the expected top of the zone of saturation. Those readings indicate that the top of the zone of maximum moisture content was relatively sharply defined. The top of this zone probably marks the top of the zone of saturation and closely approximates the water table of the alluvium aquifer.

The sloping parts of the moisture curves above the zone of maximum moisture content in April are interpreted as indicating a partly saturated zone or fringe that was caused by capillary rise from the water table at lines 3 to 5 and by slow downward drainage of residual moisture from previous periods of high water level as well as capillary rise at line 6. The thickness of the capillary fringe was only 2 to 4 feet at lines 4 and 5 in April during a period when the water table was rising at these lines. In contrast, the thickness of the capillary fringe at line 6 was 10 to 12 feet in April before the water level began to rise. However, during May and June the thickness of the capillary fringe at line 6 decreased to 6 to 8 feet as the water table rose at line 6, whereas the thickness of the capillary fringe in lines 4 and 5 increased to almost 10 feet as the water levels ~~dropped~~ declined at lines 5 and 6.

An increase in thickness of the capillary fringe and zone of drainage during a period of declining water level, and a decrease in thickness of the fringe during a period of rising water level, are usually expected (Bouwer, 1959, p. 263). The thickness of the fringe in either circumstance depends on the characteristics of the water-bearing material. Relatively slow drainage, or a thick capillary fringe, would be expected at line 6 because the alluvium below a depth of about 20 feet is composed mostly of sandy and silty clay. At lines 5 and 4 the capillary fringe or zone of drainage is thinner, because the upper part of the alluvium is composed mostly of coarse sand.

The moisture content of certain intervals at some access tubes was much higher than expected. For example, in April the moisture content in the intervals between 37 to 39 feet below the surface in MCM-6C and between 11 to 13 feet below the surface in MCM-5A was more than 55 percent instead of the expected 30 to 40 percent. These high readings probably reflect water-filled cavities in the walls of the drill holes. The May and June readings indicate that the cavity at MCM-6C may have been filled with sediment.

The holes for access tubes MCM-8C and -8D were drilled through a semipervious layer, probably clay, at a depth of about 60 feet. Water confined in the alluvium beneath this layer moved upward under artesian pressure in these holes when they were drilled and then slowly drained away after the access tubes were installed. Below a depth of 60 feet, these tubes were set in a thick slurry, but, in the interval between 10 and 60 feet, the annular spaces around the tubes were not backfilled. In the spring of 1961, recharge entering the alluvium west of MCM-8D caused an increase in water pressure beneath the confining layer and caused the water to push through the slurry packing around access tube MCM-8D and move upward relatively rapidly. This is shown on figure 7 in the depth interval between 50 and 60 feet below the surface where the high measurements of about 65 percent moisture on June 6 and 15 suggest rings of water around the tube. Further evidence of a clay confining layer may be the sharp changes in moisture content at a depth of 57 to 58 feet in MCM-8C and MCO-8. The sharp change of moisture content, instead of the gradual change ~~found~~ at lines 4 to 6, seems to indicate that a capillary fringe, such as would be expected above unconfined water, does not ~~occur.~~ form.

The water-level fluctuations at MCO-8 are difficult to interpret with the data available. This hole probably was drilled through the clay confining layer and into the Otowi Member of the Bandelier Tuff, which lies immediately below the confining layer at MCO-8. Water moved into the hole from the overlying alluvium in October 1960 before the casing was set in the hole. The perforated section of the casing is in the Otowi Member. The fluctuations of the water level in parts of March, April, and May 1961 (fig. 11) suggest fluctuations caused by changes in barometric pressure; and the general downward trend of the curve before the end of May probably indicates that some of the water in the hole drained slowly into the tuff. After the end of June 1961, the water level at MCO-8 rose rapidly as the water level rose in other holes in line 8. The time lag between the rise in water level at MCO-8 and MCM-8D and -8C may be the result of the slow lateral movement of water southward towards MCO-8.

Although the interpretation of the moisture-measurement curves and hydrographs for some holes is inconclusive, the data obtained at most of the access tubes and observation wells can be interpreted with some degree of certainty. These show that the changes in water levels and moisture content are related in time and space to the melting of the snowpack in upper Mortandad Canyon in the spring of 1961 and the infiltration and subsequent underground movement of the melt water.

The water levels were generally low at all of the observation wells when they were drilled in October and November 1960 (figs. 8, 11). Apparently the water levels declined further during the winter at TW-8A, MCO-7, and MCO-8, and probably at the other wells, also. In March the levels rose rapidly in MCO-3 and MCO-4 as the snowmelt water infiltrated and saturated the thin deposit of alluvium in the upper part of the canyon. The water in the alluvium must have begun to move downgradient, but infiltration from the ~~surface~~ stream was more than adequate to replenish the alluvium, and it remained saturated to stream level at lines 3 and 4 until the early part of May.

Late in March the ground-water body west of line 5 began to be built up into a mound with a steep eastward-sloping front between lines 4 and 5 (profile 2, fig. 8). The mound was built near the eastern front of the ~~surface~~ stream in the part of the canyon where the alluvium becomes thicker. The mound was built up rapidly, because the upper unit of the alluvium consisting of coarse loose sand absorbed water from the ~~surface~~ stream and transmitted it downward ~~at a~~ faster ~~rate~~ than the underlying sandy clay unit absorbed and transmitted the water laterally. Also, the mound was built up because the front of the ~~surface~~ stream was able to advance beyond the front of the ground-water mound after saturating only the upper part of the sand in its channel. The ground-water body became stratified, because the lower sandy clay unit transmitted water that ~~which~~ had infiltrated mainly farther upstream at an earlier date, whereas the upper coarse sand unit absorbed and transmitted water that ~~which~~ was infiltrating near the eastern front of the stream. The downward-filtering water beneath the eastern part of the stream caused the front of the ground-water mound to advance as water was accreted to the eastern slope of the mound.

The front of the ground-water mound advanced eastward in March and early April, and the approximate positions of its upper surface at different times are shown in profile 3 (fig. 8). The crest of the mound, as indicated by the highest water levels shown on figures 8 and 11, reached line 5 on April 10 or 11 and reached TW-8A on April 13 or 14, 10 days to 2 weeks after the front of the surface water in the channel ha~~s~~d passed these points. TW-8A is about 150 feet downstream from line 5. The crest reached line 6, which is 1,140 feet downstream from TW-8A, about May 2 and reached well MCO-7, which is 1,075 feet downstream from line 6, about June 27 (profile 4, fig. 8). Thus, using only approximate values, the rate of advance of the crest was about 75 feet per day between line 5 and TW-8A where there was water in the channel; 56 feet per day between TW-8A and line 6 where water was in the channel only near TW-8A; and 17 feet per day between line 6 and MCO-7 where there was no water flowing in the channel.

The difference in rates of movement of the crest above and below TW-8A is due partly to the fact that there was more alluvium to absorb the infiltrating water below TW-8A. However, the difference is also the result of the diminishing surface flow after April 17 or 18 when the front of the ~~surface~~ stream began to recede because the snowpack in the upper part of the canyon was nearly depleted. The steeply sloping front of the ground-water mound between TW-8A and line 6 began to decay and flatten when it no longer received direct recharge from the stream.

The curves on the hydrographs for MCO-5 and TW-8A are almost identical for the 4-month period of March through June 1961 (fig. 11). The rise in water levels averaged about $1\frac{1}{2}$ feet per day over a 2 or 3-week period, and occurred during the time in which the front of the ~~surface~~ stream in the channel was progressing downstream. The period of high water level at TW-8A was relatively short, because the front of the ~~surface~~ stream started to recede shortly after the ground-water crest reached the well. The slight decline ~~drop~~ in water levels in MCO-5 and TW-8A between April 15 and 25 is due to slight erosion and downcutting in the channel near the wells, causing the water in the upper part of the alluvium to drain down to the new flow level of the stream channel. The stream cut down at least half a foot at line 5.

The rates of rise of the water levels in observation wells MCO-6 and MCO-7 were considerably less than the rates at MCO-5 and TW-8A, being about 1 foot per day at MCO-6 and 1 foot per week at MCO-7. The rates were less because the alluvium at MCO-6 and MCO-7 did not receive direct recharge from the ~~surface~~ stream, and because of the greater storage space in the alluvium in the broader lower part of the canyon.

The water in the alluvium in the vicinity of line 8 ~~appeared~~ seemed to be draining downgradient until the middle of June or later, before the affects of the slug of ground water recorded west of line 8 were first noted in well MCO-8. This is approximately the same time that the water ~~appeared~~ seemed to move upward by hydrostatic pressure in hole MCM-8D. The water level in MCO-8 continued to rise slowly after the end of June as the slug of water in the alluvium progressed eastward. No increase in moisture content was recorded at MCM-10 during April, May, and June 1961.

Water levels started to ~~drop~~ decline at about the same time in MCO-3, 4, and 5--near the end of April and about 15 days after the cessation of the winter rains and snow. Most of the water probably drained from the alluvium near line 3 early in June and from near line 4 early in July. However, during heavy thunderstorms late in June, the alluvium was saturated at MCO-3 within several days and water flowed in the channel at line 3. The ground-water level at line 4 did not rise during this period, presumably because there was ~~limited~~ little recharge in that area and the water from the June storms that was moving slowly downgradient in the alluvium did not reach line 4 by the end of June.

The pattern of the decline of water levels in the canyon above line 5 in May 1961 does not necessarily indicate that much of the water, if any, moved downward from the alluvium into the Bandelier Tuff, because the water levels in the lower part of the canyon continued to rise at a time when there was no surface flow and practically no precipitation. The rise of water levels in the lower part of the canyon must have been the result of the downgradient movement of the slug of snowmelt water through the alluvium. Data concerning the movement of water from the alluvium into the tuff are few ~~limited~~. The moisture-content curves at MCM-3A and MCM-4B (fig. 7) indicate ~~that there was~~ practically no change in the moisture content of unit 2 and layer 1a of the Tshirege Member during the 3 months that the alluvium contained water. The moisture content of the part of layer 1a that is beneath the water table increased by only a few percent at lines 5 and 6, and there was no increase in moisture content in the part of layer 1a that is above the water table at lines 6 and 8. The moisture content of the tuff at most places did not increase to more than 15 percent, a moisture content which is probably less than that necessary for the tuff to transmit water.

The highest moisture content found in what seems to be unweathered tuff of the Tshirege Member was about 20 percent by volume at access tube MCM-6B. A moisture content of 20 percent might indicate that small quantities of water are moving through the tuff. A significant amount of water could be transmitted if sufficient area and time were involved. However, the tuff containing 20 percent moisture at MCM-6B may be weathered, and the moisture content of the unweathered tuff at greater depths may be less.

The data for this report are insufficient to determine whether or not water moves downward into the tuff where the alluvium rests on the Otowi Member from line 6 eastward. However, it seems unlikely that the Otowi Member would transmit appreciably more water than the Tshirege Member. Measurements of water levels at MCO-8 after June 1961 show that much of the slug of snowmelt water moved eastward past line 8 where the alluvium rests on the Otowi Member. The movements of ground water east of line 8 were not determined during the present study. The alluvium in Mortandad Canyon rests on the Otowi Member for some distance to the east, possibly as far east as Highway 4 near White Rock. The ground water that moves by underflow past line 8 might be absorbed by the Otowi Member in the lower reach of the canyon, and part of the water probably is dissipated by evapotranspiration. If the water is not absorbed completely by the Otowi Member, or dissipated by evapotranspiration, it continues to percolate downgradient through the alluvium to the vicinity of Highway 4 where the Bandelier rests on the basaltic rocks of Chino Mesa. If the ground water moves onto the basalt, it probably moves down along fractures in the basalt and eventually discharges at seeps and springs along the edge of White Rock Canyon.

Quality of water in the alluvium

Samples of water for radiochemical analysis were collected from the shallow observation wells by hand bailing on March 27, 1961, and samples for chemical analysis were collected on May 22, 1961. The radiochemical analyses were made by the Los Alamos Scientific Laboratory. No plutonium, uranium, or beta (gamma) activity higher than that of a standard (tap water) sample of water was detected. The chemical analyses were made by the Quality of Water Branch of the U.S. Geological Survey, and the analyses are shown on table 3. ~~Surface~~ Water was flowing in the stream channel to about line 5 when the samples for radiochemical analysis were collected in March, but there was no water flowing when the samples for chemical analysis were collected in May.

Usually, the recharge water derived from precipitation is relatively pure at the time it begins to infiltrate. As the water moves through an aquifer, the concentration of its chemical constituents usually increases away from the recharge area because the water dissolves minerals as it passes through the aquifer. However, in the samples collected from Mortandad Canyon in May, the concentration of most of the chemical constituents of the water in the alluvium decreased eastward (downgradient). The reasons for this general trend are not known, but part of the decrease downgradient may be due to dilution or ion exchange.

The concentrations of the calcium-magnesium and bicarbonate ions decreased downgradient in the upper part of the canyon but increased in the lower part. The decrease between observation well MCO-2 in Effluent Canyon and observation well 3 in Mortandad Canyon is in part the effect created when small quantities of waste water, discharged into Effluent Canyon from a technical area in sec. 21, T. 19 N., R. 6 E., are diluted by larger quantities of runoff in Mortandad Canyon. On the other hand, the concentrations of the sulfate ion are lower in the wastes discharged into Effluent Canyon than in the surface water in Mortandad Canyon. The reversal of the trend for the calcium-magnesium and bicarbonate ions between observation wells MCO-5 and -6 might be the result of a small slug of waste water from Effluent Canyon having been carried downstream past line 5 during ~~the~~ April when ~~there was~~ water was flowing in the channel. Also, wastes discharged into Ten-Site Canyon may have had some effect on the increase between MCO-6 and MCO-8.

Another possible explanation for the unusual trends is that the water in the alluvium might be stratified. The samples were collected by bailing rather than by pumping, thus the samples may have been obtained from different water strata at different places.

Table 3.--Chemical quality of water in the alluvium in Mortandad Canyon.

Collected from shallow observation wells May 22, 1961.

(Analysis by Quality of Water Branch, U.S. Geological Survey.)

Observation well	Equivalents per million										pH	Specific conductance (25°C)	Total hardness	Percent sodium
	Calcium-magnesium	Sodium	Potassium	Phosphate (PO_4)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride	Fluoride	Nitrate (NO_3)				
MCO-1	0.96	2.61	0.12	0.05	3.28	0.00	0.01	0.28	0.05	0.01	7.1	340	48	71
MCO-2	.76	1.83	.09	.00	2.33	.00	.01	.31	.03	.01	7.2	254	38	68
MCO-3	.64	1.57	.11	.00	1.87	.00	.25	.21	.03	.00	7.1	217	32	68
MCO-4	.52	.96	.10	.00	1.08	.00	.29	.20	.02	.00	7.0	157	26	61
MCO-5	.52	.61	.07	.00	.79	.00	.25	.16	.02	.00	6.7	119	26	51
MCO-6	.80	.65	.09	.01	.98	.00	.33	.20	.02	.00	6.5	157	40	42
MCO-7	.88	.36	.11	.00	.85	.00	.31	.14	.03	.00	6.5	133	44	27
MCO-8	1.08	.34	.08	.01	1.02	.00	.31	.14	.03	.05	6.8	156	54	23

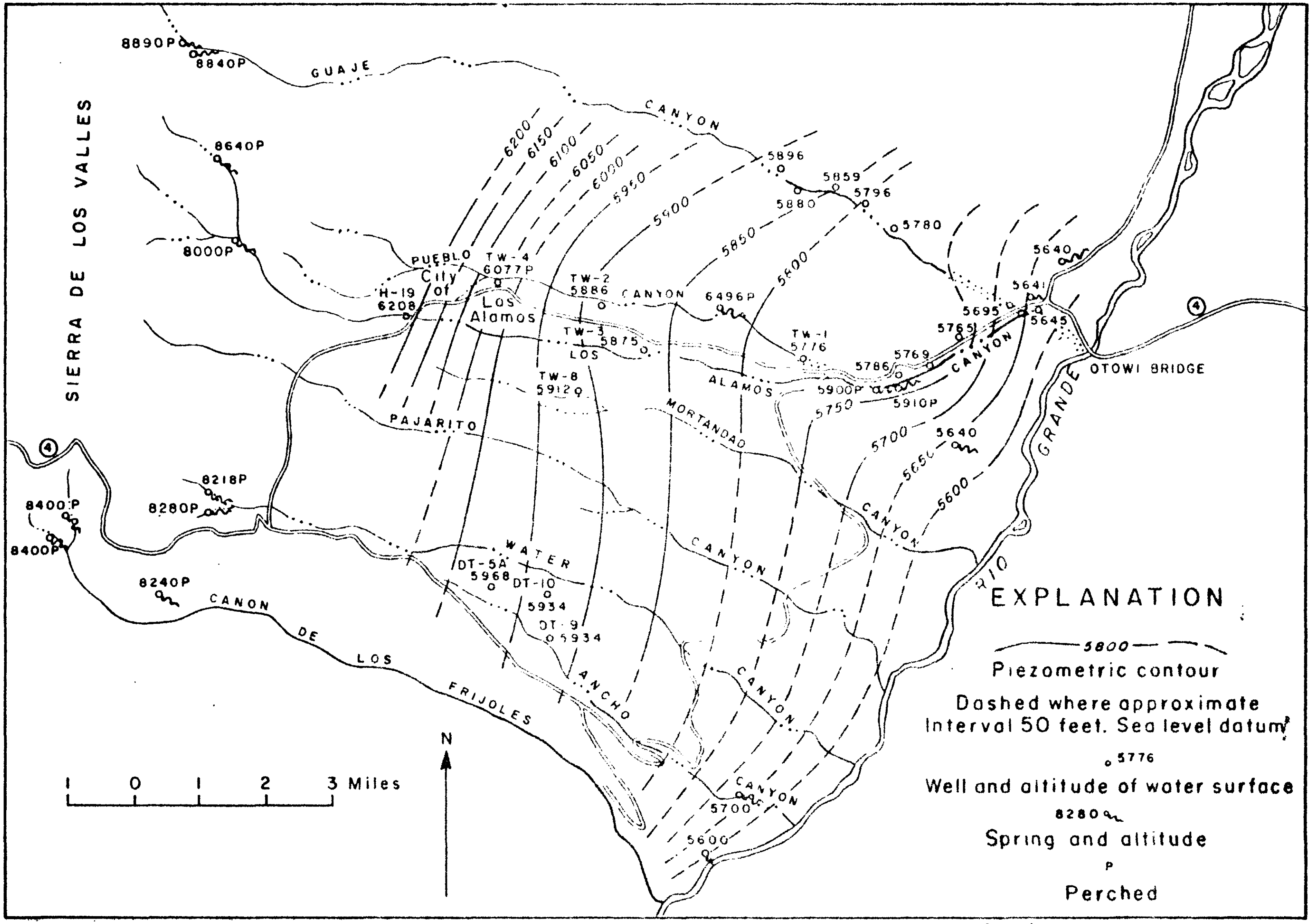
Main aquifer

At test well 8 in Mortandad Canyon, the top of the main aquifer of the Los Alamos area is between the depths of 985 and 990 feet below land surface, and the water is confined ~~under artesian conditions~~ in the lower part of the Fanglomerate member of the Puye Conglomerate. When the base of the confining bed was penetrated, water rose in the hole to 962.6 feet below land surface. The well was drilled to a total depth of 1,065 feet, about 80 feet into the upper part of the main aquifer. Unsaturated tuff, pumice, sediments, and basalt occur between the perched water in the alluvium and the main aquifer. Although no perched water is present in the unsaturated material, potential perching beds are present.

The gradient on the eastward-sloping piezometric surface of the main aquifer in the vicinity of test well 8 is about 70 feet per mile (fig. 12), and the water in the main aquifer moves

Figure 12.--Generalized contours on the piezometric surface of the main aquifer, Los Alamos [and Santa Fe area Counties], N. Mex.

generally eastward toward the Rio Grande. ~~There is~~ some discharge of ground water is to the Rio Grande through seeps and springs on the west side of the river between Otowi Bridge and the mouth of Canon de los Frijoles.



Compiled by W. D. Purtymun, June, 1961

Figure 12.--Generalized contours on the piezometric surface of the main aquifer, Los Alamos area, N Mex.

The contours on figure 12 show that the gradient of the piezometric surface of the main aquifer flattens eastward from test well 8. This may be due to changes in permeability. The general eastward slope of the piezometric surface seems to indicate that the recharge area for the main aquifer is along the flanks of the Sierra de los Valles.

Water levels

A recording gage ~~water-stage recorder~~ was placed on test well 8 in February 1961 to measure water-level fluctuations in the main aquifer. During this same period a micro-barograph recorded changes in atmospheric pressures at the Los Alamos Scientific Laboratory Administration Building at Los Alamos.

The operation of the gage ~~water-level recorder~~ was not entirely satisfactory, because ~~the well casing is crooked and~~ the float cable dragged against crooks in the inner wall of the casing and limited ~~decreased~~ the sensitivity of the recorder. The incomplete water-level record was not suitable for a complete analysis of the amount of barometric effect on the water level in the well, although general comparison of barometric changes and water-level fluctuations indicates that the water level in TW-8 fluctuates in response to barometric changes. The hydrograph of measurements and of daily high-water levels are shown on figure 13. No apparent fluctuation of the water

Figure 13.--Hydrograph of measurements and the daily highs of water levels in test well 8, January through June 1961.

level for several days may indicate a lack of sensitivity of the gage ~~recorder~~.

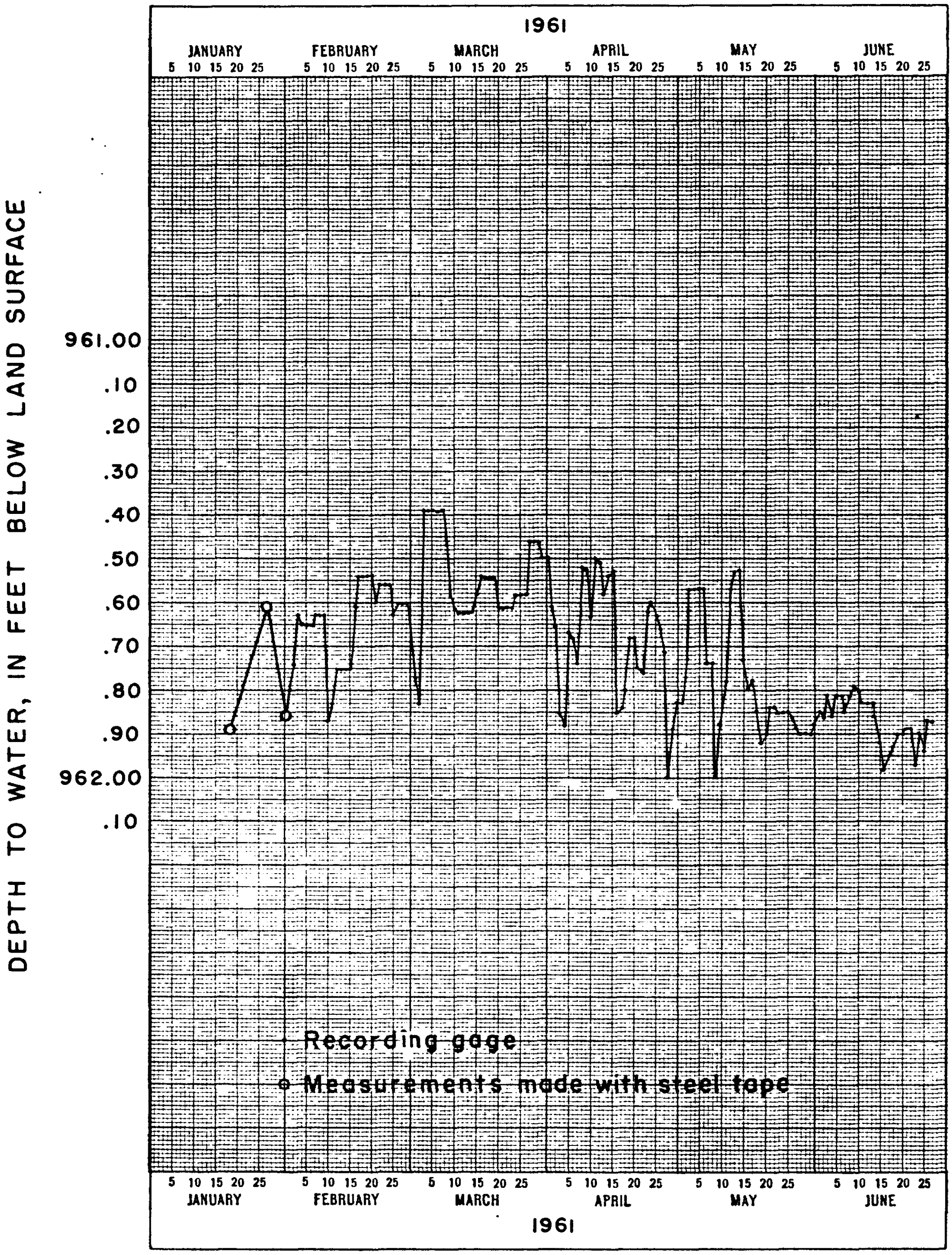


Figure 13.--Hydrograph of measurements and the daily highs of water levels in test well 8, January through June 1961.

The ~~largest fluctuations of~~ water levels fluctuated most ~~occurred during the period~~ from February to the middle of May, ~~and were due~~ owing to barometric changes that reflect high and low atmospheric pressures associated with storms that moved through the area. From the middle of May through June fluctuations of water levels were ~~are~~ small, because the barometric pressure remained high and fairly constant. The general decline of ~~the~~ water level from early March through June might be the result of periods of low pressure in March and steady high barometric pressures ~~that existed~~ during June. However, the decline might also be indicative of a previous period of less recharge to the aquifer. A longer period of record will be necessary to determine whether this is a seasonal effect related to recharge.

Transmissibility and permeability

A bailing test was made at test well 8 on December 16, 1961, to determine the coefficient of transmissibility and the permeability of the part of the main aquifer tapped by the well. The average rate of bailing was 16 gpm during the 2-hour test. The residual drawdown 5 minutes after bailing ended was 0.35 foot. Recovery to the original water level was complete 8 minutes after bailing ended. The water level recovered so rapidly that it was impossible to determine the total amount of drawdown and the rate of recovery during the first 5 minutes after bailing ended. Thus, the coefficient of transmissibility and the permeability computed from the data obtained in the bailing test are considered to be only approximations ~~of the actual values~~.

The coefficient of transmissibility is defined as the rate of flow, in gallons per day, of water under unit hydraulic gradient at the prevailing temperature through a 1-foot wide vertical strip of the aquifer. The vertical strip has a height equal to the thickness of the aquifer. The ~~determination of the~~ coefficient of transmissibility is determined from ~~is based on~~ the rate of drawdown or recovery of the water level during or after a period of pumping or bailing and the rate of withdrawal, which is the method devised by Theis (1935) and later described by Wenzel (1942). The coefficient of transmissibility is calculated to be 2,400 gpd ~~/~~ per ft (gallons per day per foot) for the part of the main aquifer penetrated by test well 8. This figure may be slightly higher or lower than the actual transmissibility, because the rapid recovery of the water level resulted in fewer measurements than are usually considered necessary to determine the rate of recovery.

To determine the field coefficient of permeability, the coefficient of transmissibility (2,400 gpd per ft) is divided by the thickness of the aquifer penetrated (80 feet). This gives a field coefficient of permeability of 30 gpd per square foot for the lower part of the Fanglomerate member of the Puye Conglomerate at test well 8.

North of test well 8 in the vicinity of test wells 2 and 3, the top of the main aquifer lies below the Fanglomerate member, and the water-bearing beds occur in the Totavi Lentil of the Puye Conglomerate. Data from pumping tests show that the field coefficient of permeability of the Totavi Lentil at test well 2 (290 gpd per square foot) and test well 3 (320 gpd per square foot) is about 10 times greater than that of the Fanglomerate member at test well 8 (30 gpd per square foot). This change in permeability in the main aquifer is reflected in the change in direction of the contours on figure 11 between test wells 2 and 8.

Using the data collected during the bailing test at TW-8, the ~~estimated~~ velocity of the water in the part of the main aquifer penetrated by the well was estimated to be ~~is~~ 0.2 foot per day, or about 73 feet per year.

Because of the time elapsed between the end of the bailing test and the drawdown measurement, the total amount of drawdown is not known. However, by using the coefficient of transmissibility, the specific capacity (gallons per minute per foot of drawdown) is estimated to be about 2 gpm per foot of drawdown (Theis and others, 1954). Thus test well 8 could supply small quantities of water for domestic or industrial use. The well can be used as a monitoring well, as have the other test wells in the Los Alamos area.

Quality of water

A sample of water for chemical and radiochemical analysis was collected from the main aquifer at TW-8 at the end of the bailing test. During the 2-hour test, the water remained turbid and the temperature of the water remained at 67 degrees F. The chemical quality of the water is similar to that of water from well DT-10, and wells TW-2 and TW-3 (fig. 12 and table 4). These wells produce water from different beds in the main aquifer.

The water from TW-8 is low in dissolved solids (216 ppm) and is soft (51 ppm hardness). The silica content~~s~~ is high (62 ppm). Calcium, magnesium, and sodium in almost equal amounts are the principal cations. More than 90 percent of the anions are bicarbonate. The water is of a good quality for domestic and most industrial use, but the formation of silica scale when the water is heated may make the water objectionable for certain industrial uses.

The ~~results of the~~ radiochemical analysis ~~are~~ is shown ~~on~~ in table 5. The analysis indicates that concentrations of the radionuclides in the water are well below tolerance limits for human use. ~~and the data are included only for background reference.~~

Table 4.--Chemical quality of water from the main aquifer,

Los Alamos County, N. Mex.

Well	TW-8[1]	DT-10[1]	TW-2[2]	TW-3[2]
Date collected	12-16-60	5-5-60	11-22-60	11-22-60
Chemical components	Parts per million			
SiO_2	62.0	65	-	-
Al	1.8	.1	-	-
Fe	.00	.00	-	-
Mn	.0	.0	-	-
Ca	11.0	12.0	-	-
Mg	5.8	2.9	-	-
Na	12.0	11.0	9.7	14.0
K	2.4	1.2	-	-
HCO_3	86.0	80.0	79.0	118.0
CO_3	0	0	0	0
SO_4	6.2	3.7	-	-
Cl	2.0	2.2	2.0	4.8
F	.7	.2	.4	.4
NO_3	3.0	1.0	.5	.8
PO_4	.19	.21	-	-

See footnotes at end of table.

Table 4.--Chemical quality of water from the main aquifer - Continued

	TW-8	DT-10	TW-2	TW-3
Dissolved solids		Parts per million		
Residue on evaporation at 180°C	216	138	-	-
Calculated hardness as $CaCO_3$ (ppm)	147	138	-	-
Total	51	42	52	77
Non-carbonate	0	0	0	0
Specific conductance (micromhos at 25°C)	158	135	139	207
pH	7.5	7.3	7.5	7.4
Color	1	0	-	-
Temp. (°F)	67	62	67	71

1/ U.S. Geological Survey, Quality of Water Branch, Denver, Colo.

2/ U.S. Geological Survey, Quality of Water Branch, Albuquerque, N. Mex.

Table 5.--Radiochemical ~~data~~ analysis of water from test well 8,

Los Alamos County, N. Mex.[1/]

Radiochemical data [a]	
Alpha activity (pc/l)[b]	
as of 2-27-61	2.7 ± 1.6
Beta activity (pc/l)	
as of 2-1-61	7.6 ± 1.1
Radium (Ra) (pc/l)	0.5 ± 0.5
Uranium (U) (µg/l)[c]	2.1 ± 0.2
Extractable alpha activity	
(net) (pc/l)	2.1 ± 1.3
Strontium - 90 (pc/l)	<0.6

1/ U.S. Geological Survey, Quality of Water Branch, Denver, Colo.

a. Sample collected 12-16-60 after 2 hours of bailing; temperature 67°F.

b. Pic~~r~~ocuries per liter (micro-microcuries per liter).

c. Micrograms per liter.

Summary of hydrology

During the present study, ~~it was determined that there is~~ a body of perched ground water in the alluvium of part of Mortandad Canyon was defined. The main source of recharge for this ground-water body is infiltration from intermittent streamflow in reaches of the canyon west of line 6. Snow that accumulated during the winter and early spring of 1960-61 in the shaded, deep, narrow upper part of the canyon was the source of most of the streamflow. During freezing and thawing cycles in the spring ~~months~~, melt water filtered into the alluvium in the stream channel and saturated the thin alluvium in the upper part of the canyon. When the alluvium in that part of the canyon became saturated, the stream began to flow. East of test well 8 the alluvium is wider and thicker, and the larger volume of alluvium provided a greater amount of storage space for infiltrating water. The infiltration and storage capacities of the alluvium downstream from test well 8 were large enough to absorb the streamflow in the main channel, and all ~~of~~ the streamflow was absorbed west of line 6 in the spring of 1961.

No data are available on the amount of melt water absorbed by the alluvium. The peak surface flow measured was about 250 gpm near line 3 on March 27. That rate of flow was sufficient to saturate the alluvium to stream level in the canyon above line 6. It was not determined how much farther east the alluvium would have been saturated to stream level and how much farther east the stream would have flowed if the peak flow had been maintained for a longer period. The downstream limit of the surface flow fluctuated upstream and downstream in response to the change in rate of flow and receded from the lower part of the canyon in late April when the flow decreased to less than 40 gpm.

After the streamflow ceased, the ground water continued to move by underflow through the alluvium, as shown by the rise of the water levels at lines 6, 7, and 8. In the part of the canyon studied, the main movement of water in the alluvium is eastward at ~~along~~ a gradient slightly steeper than the dip of the Bandelier Tuff. Measurements of changes of moisture in the tuff beneath the saturated alluvium indicate that little or no water moves from the alluvium into the Tshirege Member of the Bandelier Tuff. No direct information is available concerning the moisture changes in the Otowi Member, which is immediately under the alluvium east of the vicinity of MCO-7. The rise of water levels at MCO-8 after June 1961 indicates that much of the water moves laterally through the alluvium past line 8. Data from well TW-8 indicate that ~~there is no~~ perched water does not exist between the alluvium in the canyon and the main aquifer in the Puye Conglomerate, although potential perching beds are present in that interval. Probably little or no water moves down through the Bandelier and the Puye in the part of Mortandad Canyon west of line 8, unless the water moves eastward as well as downward.

Probable movements of wastes

The infiltration and underground movements of liquid waste probably will follow the pattern of infiltration and underground movement of precipitation in Mortandad Canyon. During dry periods, most of the waste will be absorbed and transmitted downgradient by the alluvium above line 4. However, the water derived from the melting of the snowpack in the spring of 1961 saturated the alluvium in the narrow upper part of the canyon. ~~From this it is apparent that~~ Therefore, liquid waste mixed with snowmelt ~~water~~ and water from rainstorms will occasionally flow at the surface as far east as TW-8A, and perhaps as far as MCO-7.

If any combination of conditions should occur that would occasionally move waste by surface flow into the lower part of the canyon, such as rapid runoff from heavy precipitation along with maximum discharge or accidental "spills" from the treatment plant, it is doubtful that the waste would move far below MCO-9 or MCM-10 before infiltrating. A small check dam in the valley below line 8 would be an added safety factor to insure infiltration of waste upstream from the Indian land which is east of the Los Alamos-Santa Fe County line.

If the treatment plant discharges the predicted 500,000 gallons of liquid waste per week (100,000 gallons per day for 5 days), the rate of flow will average about 70 gpm for the 5-day week, but only about 50 gpm over a period of 7 days. The ground-water mound near TW-8A in spring 1961 began to decay, and the ~~surface~~ stream began to retreat before the ~~surface~~ flow had decreased to 40 gpm. Thus, ~~it seems likely, on the basis of present~~ the data indicate that an average perennial discharge of 50 gpm of liquid waste would be absorbed above line 6 and transmitted through the alluvium below line 6. The snowmelt ~~water~~ is estimated to have saturated less than 10 percent of the cross-sectional area of the alluvium at line 8, and the volume of alluvium in this part of the canyon seems to be large enough to absorb and transmit the natural~~ly occurring~~ ground water as well as the waste liquid. However, the data obtained during the present study are not sufficient to determine the amounts of water that the alluvium will transmit.

Probably some of the waste liquid will be dissipated by moving from the alluvium into the underlying Bandelier Tuff. However, the amount of liquid will be relatively small, and it is unlikely to reach the main aquifer in the lower part of the Puye Conglomerate and the underlying Tesuque Formation. Most of the liquid will move eastward through the alluvium as far as line 8. Data are not available to predict the movements of the waste liquid east of line 8.

Presumably, the ~~argillaceous~~ clayey alluvium in Mortandad Canyon will remove much of the radioactive material from the waste by absorption, adsorption, and base exchange after the waste has moved only a short distance through the alluvium. However, it is possible that high concentrations of radioactive materials will be built up locally from the process or from evapotranspiration, even though the waste liquids are treated and are low level. Also, some sorption and base-exchange reactions are reversible; thus, if the chemistry of the ground water should be changed on occasions because of differences in the fluids infiltrating, it is possible that "fronts" of radioactive material might migrate slowly eastward through the alluvium. This possibility is unevaluated at present, but the peculiarities in the downgradient trends of the concentrations of calcium-magnesium, bicarbonate, and sulfate ions in the water samples analyzed might indicate that some waste material moves in this manner. The buildup or movement of fronts of radioactive materials, if they should occur, can probably be detected by monitoring the observation wells in the canyon.

Additional studies

The study of the hydrology of Mortandad Canyon is being continued ~~in order~~ to obtain quantitative data regarding ~~of~~ movement of water perched in the alluvium. Two wiers were constructed in upper Mortandad Canyon to determine the ~~actual~~ amount of water infiltrating into the alluvium in the canyon. Several more shallow wells and moisture-measurement access tubes were drilled at carefully selected localities to provide additional data on the contact of the alluvium and the Bandelier Tuff and the possible movement of water across this contact. These wells and tubes also provide data for determining the volume of the alluvium and its storage capacity. Pumping tests at several of the shallow observation wells will be used to determine the transmissibility of the alluvium. Routine collection of water samples will be continued before and after the treatment plant begins to discharge waste.

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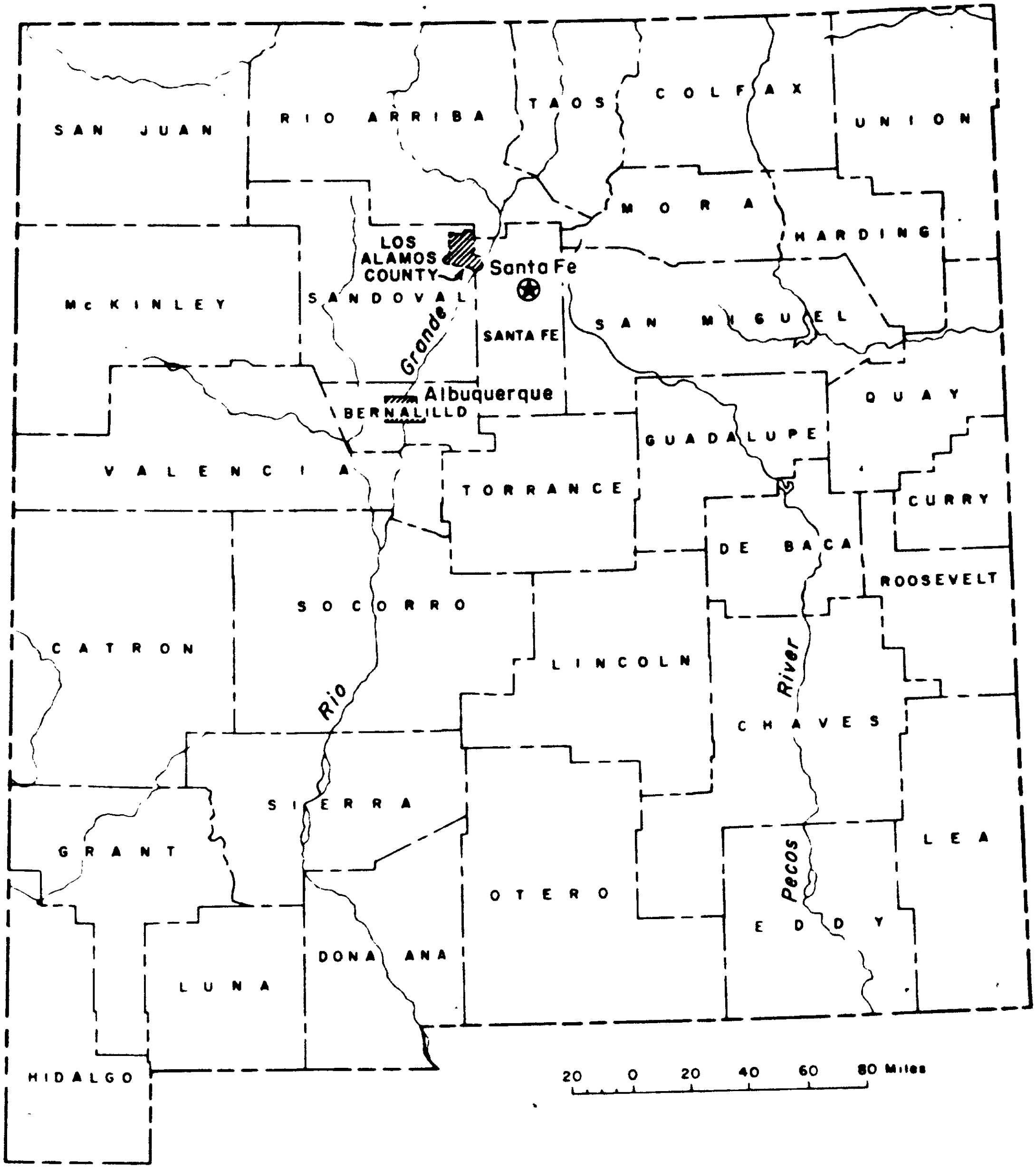


Figure 1.--Index map of New Mexico showing Los Alamos County.

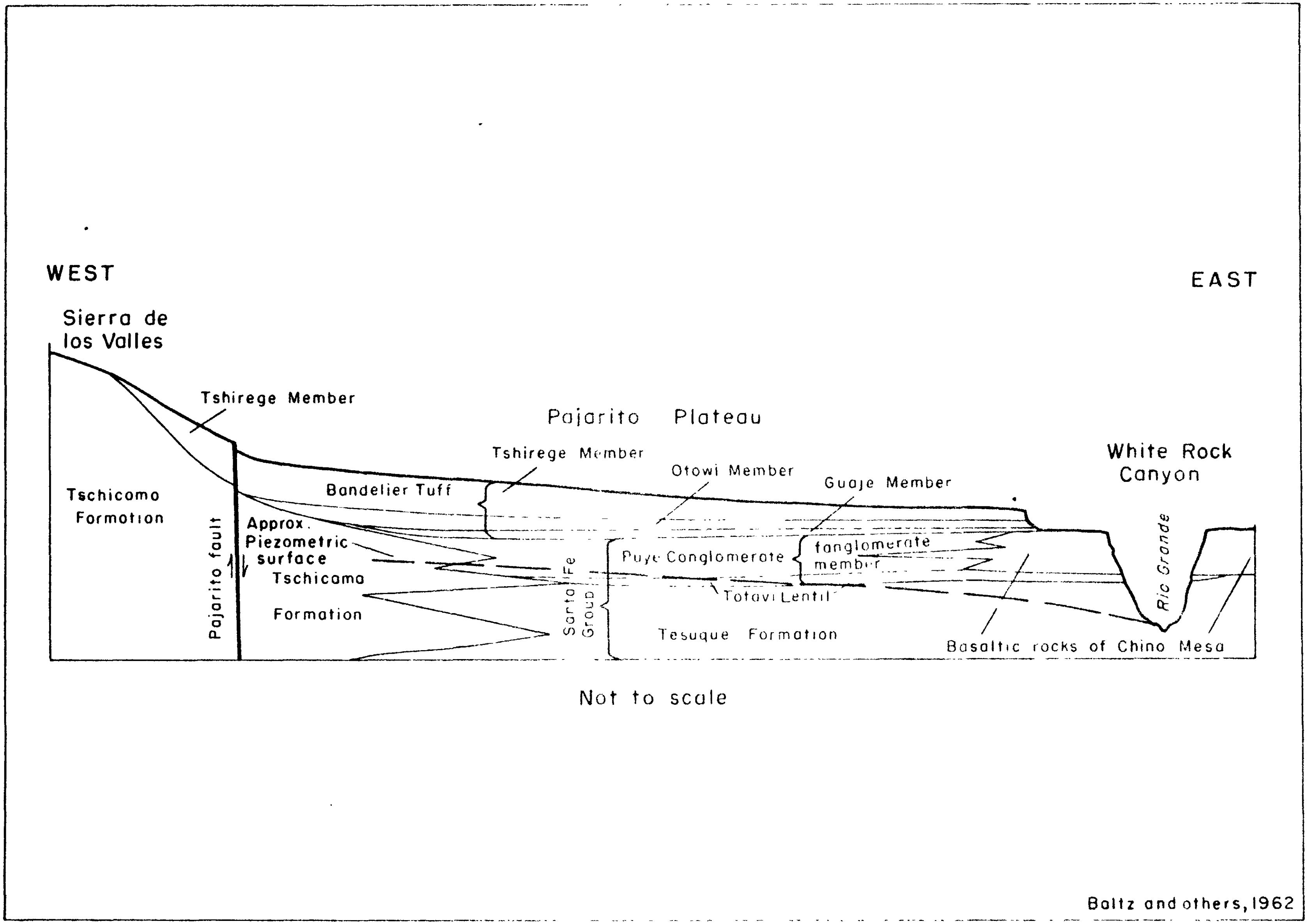
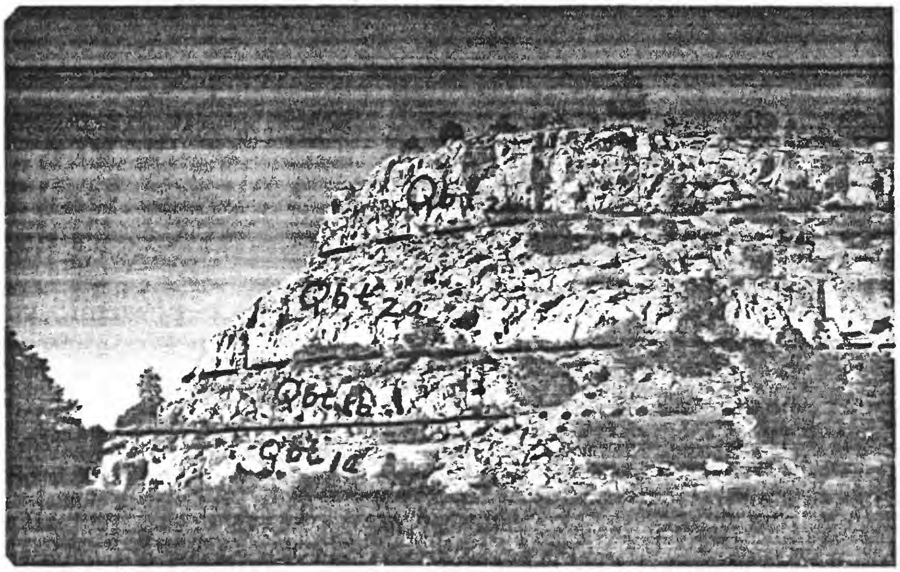


Figure 3.-- Diagrammatic cross section showing generalized stratigraphic relations of the Santa Fe Group, Tschicoma Formation, and Bandelier Tuff in the Los Alamos area.



Photograph by J. H. Abrahams, Jr.

Figure 5.--View of the north wall of Mortandad Canyon northwest of observation well MCO-8. Qbt_{1a}, layer 1a; Qbt_{1b}, layer 1b; Qbt_{2a}, layer 2a; Qbt_{2b}, layer 2b of the Tshirege Member of the Bandelier Tuff.

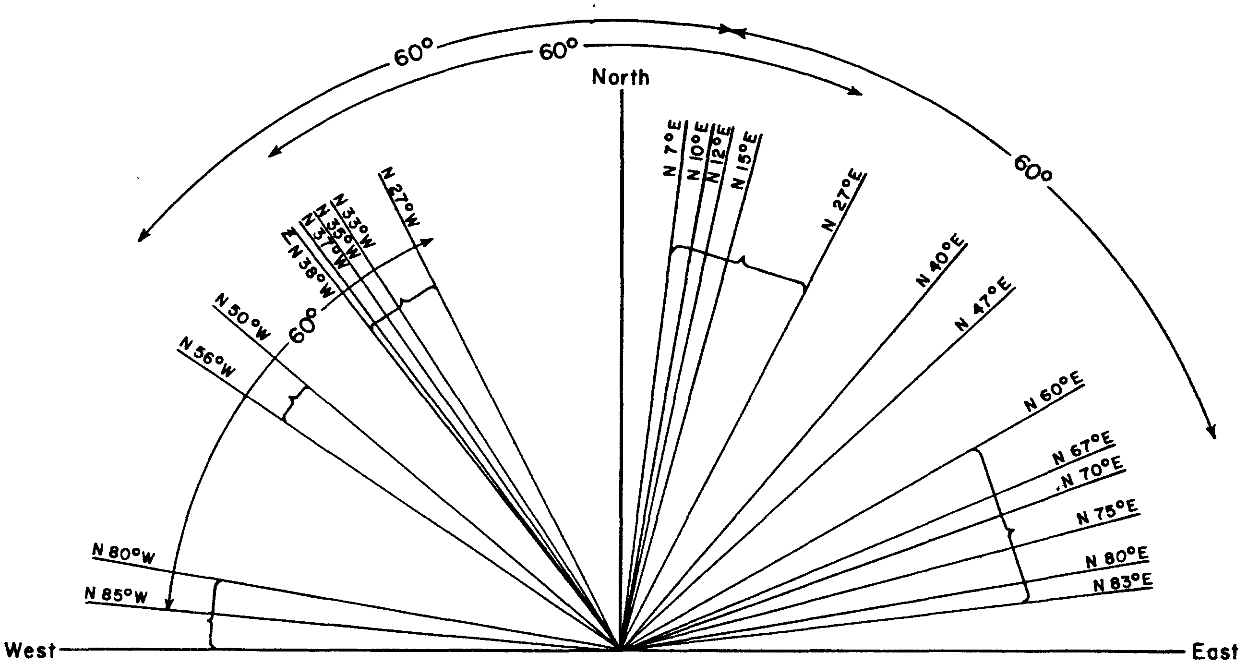


Figure 6a.-- Orientations of some of the master joints in the Tshirege Member of the Bandelier Tuff. Sets of similarly oriented joints are bracketed. Each ray represents several joints.

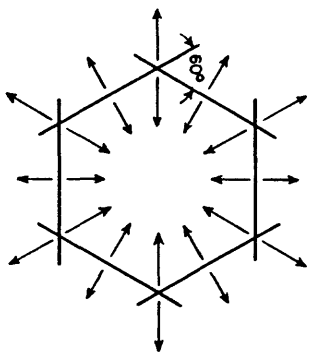


Figure 6b.--Idealized fracture pattern caused by uniform shrinkage of a homogeneous medium. Arrows indicate directions of tensional stress; sides of hexagon represent tension joints.

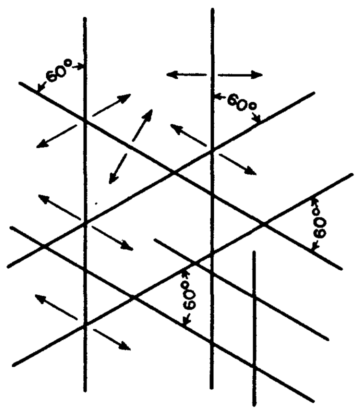
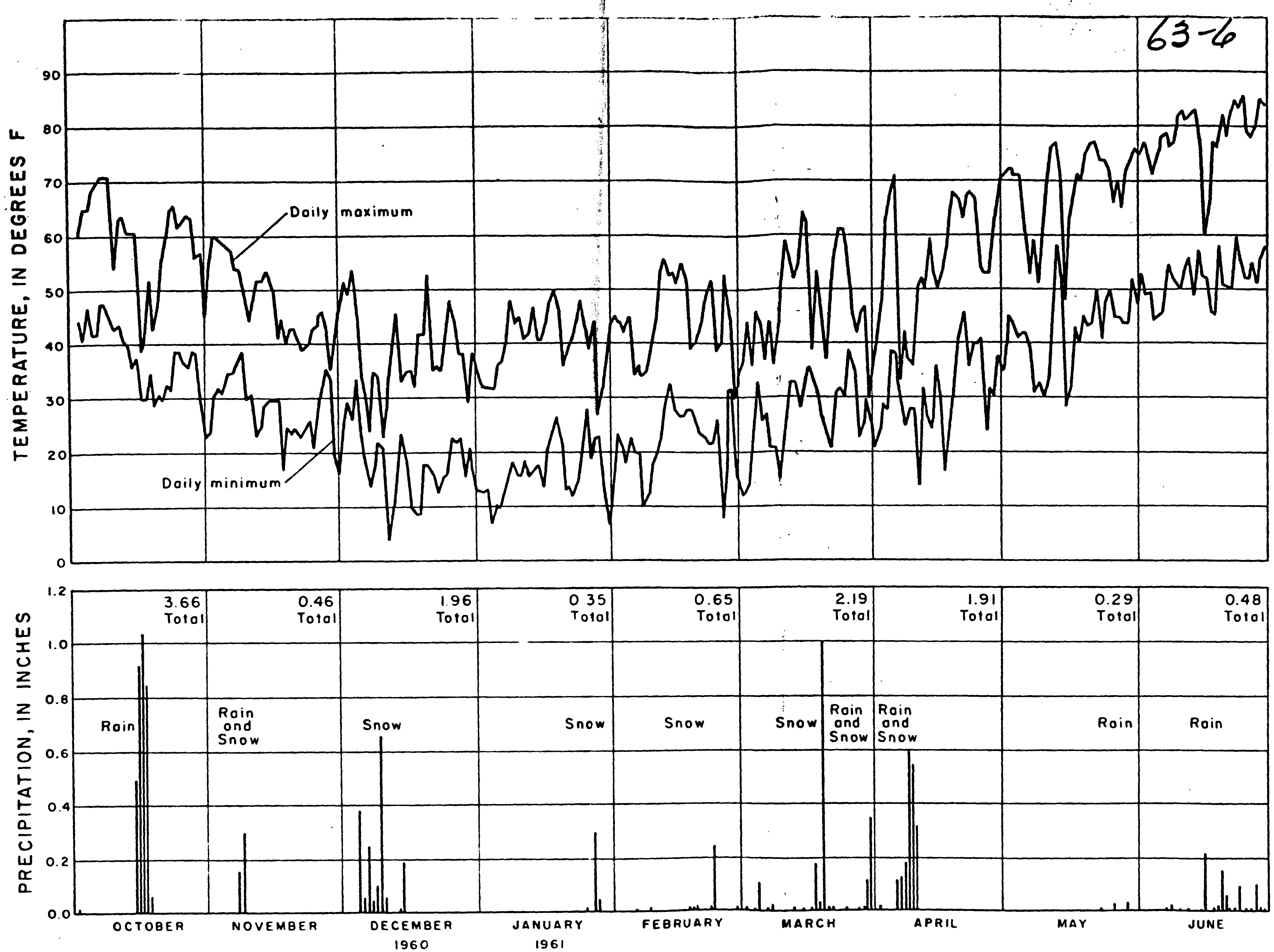


Figure 6c.--Pattern of conjugate sets of joints intersecting at 60 degrees. Arrows indicate some of the local directions of tensional stress.



63-6
TEMPERATURE, IN DEGREES F
Daily maximum
Daily minimum
PRECIPITATION, IN INCHES
3.66 Total
0.46 Total
1.96 Total
0 35 Total
0.65 Total
2.19 Total
1.91 Total
0.29 Total
0.48 Total
Rain
Rain and Snow
Snow
Snow
Snow
Snow
Rain and Snow
Rain and Snow
Rain
Rain
OCTOBER
NOVEMBER
DECEMBER 1960
JANUARY 1961
FEBRUARY
MARCH
APRIL
MAY
JUNE