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Griggs
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Geology and Ground water resources of the Los Alamos Area, New Mexico

By

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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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GEOLOGY AND GROUND-WATER RESOURCES OF THE LOS ALAMOS AREA, NEW MEXICO

by

R. L. Griggs

U. S. Geological Survey

ABSTRACT

This report describes the geology and the occurrence and availability of ground water in an area surrounding Los Alamos, New Mexico. The study on which the report is based was made by the Ground Water Branch of the Geological Survey with funds furnished by the Atomic Energy Commission.

The Los Alamos area is in north-central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe. As used in this report, the area is about 20 miles long in an east-west direction and about 10 miles wide in a north-south direction. The town of Los Alamos is near the center of the area.

The rocks of the area are of late Tertiary and Quaternary age. They consist of volcanic and sedimentary rocks that accumulated at the western side of the Rio Grande depression. For the most part, the area lies on the eastern flank of the Jemez Mountains , a volcanic eruptive center that stands athwart the zone of faulting at the western margin of the Rio Grande depression. The western edge of the area is near the center of these volcanic rocks and from there the area extends eastward across a segment of the interior mass of flows and an outlying apron of tuff that lies on the sedimentary and volcanic rocks of the Rio Grande depression.

The volcanic rocks of the Jemez Mountains consist mainly of the Tschicoma and Tewa groups with the former represented by two map units which consist of (1) latite and quartz latite and (2) pyroxene andesite; and the latter group represented by the (1) Bandelier tuff, (2) Cerro Toledo rhyolite, (3) Cerro Rubio quartz latite, and (4) Valles rhyolite. The Tschicoma group forms the interior mass of flows of the volcanic center. The Bandelier tuff forms the outlying apron of tuff. The Cerro Toledo rhyolite, the Cerro Rubio quartz latite, and Valles rhyolite are volcanic domes associated with the collapsed interior of the volcanic center. In addition, an unnamed body of sediments occurs in the Valles caldera, a portion of the collapsed interior of the volcanic center.

The suite of rocks of the Rio Grande depression are referred to the Santa Fe group. Within the area this group is represented by three main map units. One is an undifferentiated sequence of arkosic sandstone and siltstone with some included basalt. Another, the Puye conglomerate, is composed mainly of latitic debris derived from the interior mass of the Jemez volcanic area, but it also includes some interbedded basalt and a lentil of arkosic conglomerate. The third unit is a thick sequence of basalt.

Mapping and subsurface work indicate that the stratigraphic units are complexly interralated. The mapping shows that the units of the Santa Fe group interfinger with each other. The subsurface work indicates that two units of the Santa Fe group, the undifferentiated sequence and the Puye conglomerate, interfinger with the Tschicoma group of the Jemez Mountains volcanic area.

Adequate water resources for the town of Los Alamos are not available in the immediate vicinity of the town. However, water in quantities adequate for the present population (14,000) occurs at both the eastern and western margins of the area. In both places the surface waters cannot be used because of legal restrictions. Water of the streams in the Valles caldera, in the western part of the area, is utilized by Jemez Indians who have primordial rights to the flow. The flow of the Rio Grande, at the east margin of the area, also is completely appropriated by downstream users. Ground water in the sediments of the Valles caldera is unavailable as the present investigation has indicated that the small water bodies present are in close connection with the adjacent streams, and pumpage would decrease the stream flow. Ground water in the undifferentiated sequence of the Santa Fe group in the eastern part of the area represents the only source of supply available. Between 1946 and 1952 eleven supply wells were completed in these sediments. The study on which this report is based indicates that these wells are capable of supplying one billion gallons of water annually, the amount necessary for the town.

INTRODUCTION

PURPOSE AND SCOPE OF THE REPORT

This report is based on ground-water investigations requested in the early part of 1949 by the Atomic Energy Commission. Prior to that time the water supply for the Los Alamos project had been developed piecemeal, both as a result of numerous changes in plans for the size of the project and as a result of an absence of information concerning the occurrence of water in the area.

From the early part of 1943, when the project was started, through 1945, a water supply was obtained from small springs and small spring-fed streams that emerge on the mountain slope west of the town. These sources were developed one by one as the town grew during the war years. At the end of the war in 1945, however, all available surface water on the mountain slope was being utilized, and the water requirements of the project exceeded that available from the mountain sources. Shortly thereafter, in the early part of 1946, Black and Veatch, a consulting firm , Kansas City, initiated a test drilling program about 10 miles east of the project. This program led to the completion of six wells by the end of 1948 in Los Alamos Canyon, a tributary to the Rio Grande. By the time these wells were completed, plans for a larger project demanded additional water by the beginning of summer, 1951; and Black and Veatch suggested development of ground water in a large volcanic depression some 10 miles west of the project.

Shortly thereafter the Geological Survey was requested by the Atomic Energy Commission to undertake a detailed study of the ground water of that area and to prepare a report describing the availability of water and its relation to the geology in order to provide a basis for solving the water problems. Later, the study area was enlarged to cover also the area east of the volcanic depression. Some work on basic data is still in progress (1955), and some additional work probably will need to be done on a continuing basis, but the following report contains sufficient information needed to solve water-supply problems that may arise.

PREVIOUS WORK IN THE LOS ALAMOS AREA

A number of brief memoranda and several reports as cited below and listed at the end of this report have been written on the water supply for Los Alamos. Other reports were completed while this investigation was in progress. These memoranda and reports have not been published, and only a relatively small amount of the results of the work on the basic geology of the area has been published.

Most of the brief memoranda were written by Army personnel during the war years when Los Alamos was expanding rapidly. These described the small spring-fed surface water supplies which are still in use. One of these sources was being developed by the construction of a small dam when Los Alamos was selected in late 1942 as one of the project sites for the development of the atomic bomb. H. W. Yeo, (1942) of the Corps of Engineers, who prepared the earliest memorandum on available water in the area, visited the site in November 1942, and described a 28 acre-foot reservoir that was being built by the Los Alamos Ranch School for Boys whose plant was taken over shortly thereafter by the Government. Yeo estimated that the reservoir, fed by a minimum flow of about 100 gallons per minute, would supply the water needs of a town of over 1,400. He also noted the presence of water in canyons to the north and south. When a water shortage developed in the early spring of 1943, D. C. Bondurant (1943 and 1943a) twice visited the project and prepared two memoranda on stream flow on the mountain slope west of the town. Later that spring and again in the summer R. E. Lawrence (1943 and 1943a) examined the area and wrote two memoranda which led to the construction of pipe lines that tap practically all of the small surface sources present in the immediate area. In late 1943 the Albuquerque District of the Corps of Engineers wrote a brief summary of existing facilities and recommended some improvements (Ruble, 1943).

The firm of Black and Veatch began water-supply investigations in the area in the early part of 1946. Their work lasted through 1951 and in part was made in conjunction with work of the Geological Survey. Formal reports discussing existing and future supplies were prepared by Black and Veatch in 1946 (Lawrence, 1946) and in 1948 (Brown, 1948). In 1948 Harold T. Stearns described briefly the geology and ground water of the Valles caldera, the large volcanic depression at the top of the mountains west of Los Alamos. Black and Veatch prepared a resume of their work in 1951 (Brown, 1951), a lengthy report presenting an engineering analysis of the existing water supply and distribution facilities, the use of water at the town, the capacity of existing sources, and some possible sites for additional sources. As a part of the investigation by the U. S. Geological Survey three semiformal reports, concerned mainly with guiding ground-water development, were released to the Atomic Energy Commission during 1950 and 1951.

The memoranda written during the war years are of interest mainly for their record of the water-supply difficulties that harassed the town during that period. The reports written after the war give additional information which has been of considerable value to this investigation.

Although much previous work has been done on the basic geology in the surrounding region and several reports mention a few of the geologic units that occur at Los Alamos, little material dealing specifically with the area has been published.

Several geologists attached to the early armies of exploration and geologic and geographic surveys of the West visited the region between 1850 and 1875. Reports of these early surveys were published in the 1870's and deal largely with the broad geologic character of the country; however, they include Hayden's original description of the Santa Fe formation (Hayden, 1873), and Cope's (Cope, 1877) description of the fauna from this unit which had been collected by himself and by the Wheeler Survey party of 1873. Graton (Lindgren, Graton, and Gordon, 1910) visited the Bland mining district, some 15 miles southwest of Los Alamos, in 1905 and wrote a brief description of the geology and occurrence of the ores of that district. C. S. Ross made a preliminary investigation of the Valles Mountains in the 1920's. At that time base maps for geologic work were inadequate and Ross postponed work after a brief study. Kirk Bryan probably made a number of excursions into the area from about 1910 through the 1930's. A few of his observations on the eastern part of the area are incorporated in a report on the geology and groundwater conditions of the Rio Grande depression (Bryan, 1938). Two of Bryan's students, H. T. U. Smith and C. S. Denny, worked in neighboring areas. Between 1932 and 1935 Smith studied and mapped the geology of the Abiquiu quadrangle whose southern boundary lies a few miles north of Los Alamos. In this work he dealt briefly with some geologic units that also are present in the Los Alamos area (Smith, 1938). Denny spent six weeks in the Española Valley, about 1939. His paper (Denny, 1940) describes the Santa Fe formation of the Española area and covers sediments exposed at the north end of White Rock Canyon. V. C. Kelley, in connection with pumice studies for the Atomic Energy Commission, prepared a planimetric map and a brief geologic report on the Los Alamos area in 1948. This work (Kelley, 1948) has not been published.

Contemporary work on the basic geology of the region has been extensive. C. S. Ross and R. L. Smith have been engaged since 1946 in a detailed study of the Jemez volcanic series, representative units of which immediately underlie the greater part of the Los Alamos area. Field work on their project is essentially complete. Zane Spiegel and Brewster Baldwin (Spiegel and Baldwin, 1955) recently studied the geology and ground water of the Santa Fe area, some 20 miles to the southeast.

FIELD WORK FOR THIS REPORT

The field work for this report was started in June of 1949 and was largely completed by April 1952. During this period, the Survey's work was divided between two projects that were separated in many respects but which overlapped to a large extent as both projects dealt with the geology and hydrology of the area. The main project concerned the water supply with which this report deals. The other project concerned the underground movement of waste products discharged by the Los Alamos laboratory. Both projects were started within a few days of each other, and during the course of events work was commonly shifted from the one project to the other in order to coordinate activity with exploratory drilling that was carried on intermittently as an important phase of both projects.

The exploration for the water supply was centered mainly in two areas, the eastern part of the Valles caldera, some 10 miles west of the townsite, and in Guaje Canyon, some 10 miles northeast of the townsite. Work on the waste project extended from the townsite eastward and southward to the limits of the accompanying geologic map (Plate 1). An additional report is to be written on the latter project, but the work is mentioned herein as some of the basic data collected are pertinent to the geology and hydrology of the entire area and must necessarily be included in a report on water supply.

At the time the projects were started, 1949, the need for additional water for Los Alamos was acute, and little was known of the occurrence of ground water in the area. The view was prevalent locally that the well field in Los Alamos Canyon developed between 1946 and 1948 was being depleted rapidly, and there was an inclination to attempt to locate a separate source of supply. Previous work (Stearns, 1948) had indicated the presence of ground water in the Valles caldera. Also, an idea existed that available water might be present beneath deep canyons adjacent to the townsite area. The Atomic Energy Commission had awarded a contract for extensive drilling in the Valles caldera and for one deep hole in Los Alamos Canyon, in the town area. Another contract had also been awarded for exploratory drilling to locate waste products beneath the

Pajarito Plateau. A part of the Survey's work was the selection of sites for the drill holes, the description and interpretation of materials collected from them, and the selection of zones for the placement of sections of well screen. Another phase of the work consisted of running pumping tests to determine the hydraulic coefficients of water-bearing zones and evaluation of the supply. When in the fall of 1949 pumping tests in the Valles caldera showed that the removal of water from that area would affect the flow of nearby streams, exploration for a water supply was shifted to Guaje Canyon, where five production wells were eventually completed. This shift entailed studies of geologic units along the east edge of the Pajarito Plateau and included a number of pumping tests.

Concomitantly with these exploratory programs for water, additional drilling and hydrologic studies were carried on in connection with the waste project. During periods of relative quiet in the drilling programs, a geologic map of the Los Alamos reservation and vicinity was prepared. The mapping was done on aerial photos having a scale of approximately 1:31,680. The data were then transferred with a Kail plotter and by visual inspection to a manuscript topographic map having a scale of 1:20,000. This map was later reduced to a scale of 1:24,000 and accompanies this report.

ACKNOWLEDGMENTS

Many of the engineering phases of the investigation were made under the supervision of C. V. Theis and C. S. Conover, successively District Geologist and District Engineer for the Ground Water Branch of The Geological Survey in New Mexico. These men were actively engaged in some of the pumping tests, and they made interpretations of most of the pumping tests. Messrs. R. J. Councill and J. E. Weir, Jr. directly assisted the writer. Mr. Councill was assigned to the project from June 1949 to June 1951. Mr. Weir was assigned to the project from May 1951 to April 1952. In addition, almost everyone in the Albuquerque office of the Ground-Water Branch was assigned to some phase of the work at one time or another.

It is a pleasure also to record thanks to personnel of the Atomic Energy Commission and to the Zia Company at Los Alamos. Especial thanks are due R. P. Johnson and P. A. Wilson of the Commission, and Richard Crook, L. F. Alexander, and R. E. Armstead of the Zia Company.

To Messrs. C. S. Ross and R. L. Smith of the Geologic Division of the Survey the writer feels a particular indebtedness. These men were engaged in a study of the geology and petrology of the Jemez volcanic series from 1946 to 1952, and they were never hesitant in exchanging information with the writer on the geology of the region. To G. H. Wood of the Geologic Division the writer is indebted for advice on the late Tertiary sediments and the regional structure of the Rio Grande depression. Mr. Wood also aided the writer in compiling the geologic map.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

The Los Alamos area is in north-central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe (see figs. 1 and 2). As used in this report, the boundaries of the area are coincident with the boundaries of the accompanying geologic map which essentially covers Los Alamos County created in 1949 and overlaps on the west into northeastern Sandoval County and at the northeast extends into northwestern Santa Fe County. The Los Alamos area trends northwesterly and is approximately 20 miles long and 10 miles wide with the geographical center lying close to longitude 106°20'W., and latitude 35°53'N.

The area is relatively inaccessible, in part because of security regulations that protect the town of Los Alamos and in part because of the sparsity of good public roads through the isolated mountainous region. State Highway 4, the only improved public road, extends through the eastern and southern portions of the area, crossing an unimportant part of the Los Alamos reservation. This highway is asphalt surfaced in places and is generally considered a good road, but it is impassable through the mountains in winter. An improved access road leads from State Highway 4 into the Frijoles Canyon monument at the south edge of the area, and a few unimproved roads, most of which reach dead-ends, also branch from this highway. The Los Alamos reservation can be crossed on Highway 4 without restriction, but the main parts of this area may be entered only through special permission on access roads leading from this highway.

The town of Los Alamos with approximately 14,000 people (1952) is the only large community. The village of White Rock was built by the Atomic Energy Commission to accommodate the employees of construction contractors. The village has a widely varying number of inhabitants from time to time, but the population seems to range from about 1000 to perhaps 2000. Totavi, a contractor's camp, has a population of about 100. The Frijoles Canyon Monument at the south edge of the area has about 10 permanent residents.

PHYSIOGRAPHIC SETTING

The Los Alamos area lies in a region where four main physiographic provinces are represented. (See fig. 2.) Two of these, the Southern Rocky Mountain and Basin and Range provinces, are of significance to the regional setting of the area. The Southern Rocky Mountains extend southward from Colorado as two separate north-south prongs, one of which lies east, the other west of Los Alamos. Both prongs die out a short distance south of the general latitude of the area. The eastern prong is represented by the prominent Sangre de Cristo Range whose abrupt west front is about 20 miles to the east. (See fig. 3.) The range dies out about 50 miles to the southeast. The western prong is represented by less distinct, discontinuous units, the most southerly of

Plate 2.—View looking westward to Jemez Mountains volcanic center from near western foot of Sangre de Cristo Mountains. The interior mass of the volcanic center is on the horizon and the Pajarito Plateau is visible at the base of the steep slopes. Badlands of Española Valley in foreground.

which is the Sierra Nacimiento. The axis of this range is some 20 miles west and its indefinite eastern front lies a few miles beyond the western margin of the area. The range dies out about 40 miles to the southwest. Extending northward from Mexico and separating these mountain masses north of their southerly terminations is the Rio Grande depression, one of the large rift valleys of the Basin and Range province. The Los Alamos area is in the Basin and Range province and essentially adjacent to the western prong of the Southern Rocky Mountains.

In a more limited perspective, the area lies mainly on the eastern flank of the Jemez Mountains volcanic center. (See fig. 3.) The volcanic center stands as a circular mountainous element athwart the boundary between the Rio Grande depression and the western prong of the Southern Rocky Mountains. In part, the volcanic rocks overlap the Rocky Mountain structure on the west and in part it extends eastward into the Rio Grande depression. The volcanic center consists of a steep-sided interior mass which contains a central area of collapse and discontinuous apron-like plateaus which surround the interior mass. Specifically, the Los Alamos area occupies a parallelogram-shaped strip extending from the center of the collapsed portion of the Jemez volcanic center eastward across a segment of the steep-sided interior mass and one of the adjacent plateaus onto plains and mesas in the central part of the Rio Grande depression.

TOPOGRAPHY AND DRAINAGE

At the eastern margin of the Los Alamos area is the Rio Grande, locally bordered by plains and in part following White Rock Canyon. Immediately west of the plains and the west wall of White Rock Canyon there is a high plateau whose surface rises gently to the west. Near the medial line of the area this plateau abuts against the Sierra de los Valles, the interior mass of the Jemez Mountains volcanic center. This mountain rises abruptly from the plateau and culminates in a group of serrate peaks and saddles west of which lies the Valles caldera, the conspicuous portion of the collapsed interior of the volcanic center.

The narrow belt of plains that fringe the Rio Grande through the Española Valley barely extend into the Los Alamos area. For the most part they lie north of the Otowi bridge, in the extreme northeast corner of the area where they are present on both sides of the Rio Grande. These plains also occupy a small area to the east of the river between Mesita Mesa and the northern tip of Chino Mesa. North of Otowi bridge the plains are relatively flat to gently sloping, though commonly entrenched by shallow arroyos and surmounted by low hills. As White Rock Canyon is approached from the north the plains are surmounted by high buttes and mesas such as Mesita Mesa. At their west margin they are sharply separated from the plateau area by the Puye escarpment, a steep sinuous cliff from whose lower levels a fringe of hills extends eastward onto the plains.

Although the west wall of White Rock Canyon extends northward to Otowi bridge, the canyon proper starts at the north end of Chino Mesa, immediately south of old Buckman, where the Rio Grande enters a narrow gorge that separates Chino Mesa from the plateau to the west. From here the river follows the gorge southwestward for 14 miles, the entire length of Chino Mesa. Through this distance the sheer canyon walls are about one thousand feet high. A very few side canyons, short and abrupt, breach the wall on the east side, and similar breaks by larger canyons are fairly numerous in the west wall. The eastern boundary of the map area overlaps Chino Mesa for about 3 miles and then follows the axis of the canyon southwestward for an additional 3 miles.

Lying between the plains or the west wall of White Rock Canyon and the Sierra de los Valles is a high plateau which Hewitt (1938, p. 34) called the Pajarito Plateau. He applied the name to "the plateau extending from the Chama River to Cañada de Cochiti and lying between the Jemez Mountains (Sierra de los Valles) and the Rio Grande". This plateau, capped by volcanic tuff for the most part, covers a stretch of more than 30 miles parallel to the Rio Grande and is one of the prominent volcanic plateaus that surround the Sierra de los Valles. Its surface which originally was continuous is dissected by numerous narrow canyons that entrench and cut through the tuff cap as they pass from west to east across the high plateau. As a result the country is characterized by long finger-like mesas, whose upper surface rise gently to the west and abut against the mountains. These elongate mesas with steep walls are known locally as potreros. The rugged terrain, difficult of access because of the narrow entrenching canyons between the potreros, was found inviting by early Indians who apparently liked the natural protection afforded by the rough country. Cliff-dwelling ruins in the canyon walls and house ruins on the tops of the potreros are numerous, and the plateau and its ruins were made famous by the ethnologist, Adolph Bandelier.

Steep, irregular slopes, immediately west of the Pajarito Plateau, are a segment of the crescent-shaped mass of the Sierra de los Valles. This mass, after having been severely eroded and decapitated, is not a text-book example of a vòlcanic cone, but its dark slopes, ending in grass-crested peaks, form an impressive unit. To set apart this physiographic unit the name Sierra de los Valles, (Range of the Valleys) the terminology of the early Spanish, is used herein instead of the term Jemez Mountains inasmuch as the latter designation is used commonly to include both the interior mass of the volcanic complex, its surrounding apron of plateaus, and even the adjacent Nacimiento Mountains and San Pedro Mountains.

The Valles caldera, with only its eastern half included in the map area, lies directly west of the high peaks that flank the Pajarito Plateau. This depression is the surface expression of a portion of the collapsed interior of the Jemez Mountains volcanic center. The entire depression is an almost circular, bowl-shaped sink about 12 miles in diameter with an outer margin marked by a steep, inward facing escarpment whose upper limit is marked by a serrate arrangement of peaks and saddles along the curving crest of the Sierra. The floor of the sink is grass-covered and lies from about 500 to nearly 2,000 feet below the surrounding rim. This floor is studded with numerous mound-like volcanic domes that divide the depression into a network of valleys.

Plate 4.--View looking northward across eastern part of Valles caldera. The peaks on the right are on the crest of the Sierra de los Valles and just west of Los Alamos. The forested mound on the left is a dome within the caldera.

Altitudes in the area range from about 5,360 to 10,920 feet above sea level. The lowest altitude is at the extreme southeast corner of the area, in the bottom of White Rock Canyon. Farther north, at the east-central part of the map, the river is near 5,500 feet. To the west, the Pajarito Plateau, with a southeasterly slope, stands mainly between 6,400 and 8,000 feet. Above the plateau, peaks along the Sierra de los Valles range to more than ten thousand feet. Pajarito peak west of Los Alamos extends to 10,041 feet and Caballo peak to the northwest reaches 10,469. Cerro Toledo on the north rim of the Valles caldera reaches 10,049 feet and Turkey Mountain to the north of Cerro Toledo reaches 10,920 feet. Within the caldera elevations range from about 8,500 feet on the floor to 10,332 at the top of Cerro de Abrigo, one of the central domes. A short distance beyond the western part of the area some peaks rise above 11,000 feet. Thus, the total relief is more than 5,500 feet.

Local relief is pronounced throughout the area. All along White Rock Canyon the walls are nearly perpendicular, and approximately 1,000 feet high. Numerous canyons of the Pajarito Plateau commonly are 200 to 400 feet deep with walls that are in part vertical. The canyons on the east flank of the Sierra de los Valles also are rugged although the walls are not as steep as those of White Rock Canyon or those of the canyons of the Pajarito Plateau. However, elevation differences of over 1,000 feet occur in places between canyon floors and adjacent peaks of the Sierra. Within the Valles caldera steep sided volcanic domes stand as much as 1,500 feet above the floors of the adjacent valleys.

All of the run-off of the area goes to the Rio Grande, and the rim of the caldera acts as a local divide and gives rise to a unique drainage pattern. East of the rim the canyons that originate on the Sierra and on the Pajarito Plateau follow a more or less direct easterly course to the Rio Grande. The surface waters of the Valles caldera drain westward from the depression and follow the circuitous course of Jemez River around the south side of the volcano before entering the Rio Grande some 40 miles south of the area. Of the streams east of the rim, only one, the Rito de los Frijoles, carries water to the Rio Grande throughout the year. Other main canyons of the eastern part of the area have in recent times contained a perennial flow for short distances beyond the east margin of the Sierra, but since the advent of Los Alamos the small flows of these canyons have been intercepted on the lower slopes of the mountain by the town's water system. The base flow of these streams, at points immediately above their interception, ranges from about 25 gallons per minute in Pajarito Canyon to about 150 gallons per minute in Guaje Canyon. With the exception of Rito de los Frijoles, only after heavy summer storms do the east slope canyons carry water to the Rio Grande.

Two main streams, the East Fork of Jemez River and the Rito San Antonio, drain the Valles caldera. The East Fork drains the southern and the Rito San Antonio the northern part of the depression. The two streams unite about 9 miles west of the area to form the main stem of Jemez River which, after following an arcuate course around the southern side of the Jemez volcanic pile, joins the Rio Grande.

CLIMATE AND VEGETATION

The climate is semiarid with a wide range of conditions from the eastern to the western part of the area. The plains adjacent to the Rio Grande receive an average annual precipitation of about 10 inches. Westward, the precipitation increases fairly rapidly with altitude. The Frijoles monument station, in a deep canyon of the Pajarito Plateau, receives about 15 inches, and the west margin of the plateau receives about 18 inches. Little information is available for the high parts of the mountains or the caldera area, but these localities are from 1,000 to 3,000 feet higher and probably receive an average of about 20 inches or more annually.

The heaviest precipitation occurs during the warm months from local thunderstorms that generally occur in the middle of the day. Approximately three-fourths of the annual precipitation comes during the six-month period April through September, and about one-third of the annual precipitation generally falls during a definite rainy season in July and August when the local thunderstorm activity is greatest. In some years more than half of the precipitation falls during these two months. In winter the snowfall is light on the plains, but it increases to about 50 inches at the west edge of the plateau, and it may approach 100 inches in the higher parts of the mountains, where Highway 4 generally is blocked by snow from the latter part of November through February or March.

Temperatures vary with altitude. For example the average July temperature at the lower elevations is about 75 degrees while at Los Alamos it is about 67 degrees. The average January temperature on the plains is about 29, and at Los Alamos it is 27. A one-year record (1949-1950) of temperatures in the Valles caldera indicated an average July temperature of about 54 degrees and an average January temperature of about 15 degrees.

The types of vegetation vary with altitude and exposure, and a general change takes place from east to west with corresponding increase in altitude. The plains of the northeastern part of the area are a semi-desert grassland with vegetation of the upper Sonoran type. The grasses are three - awns, some sacaton and galleta, and lesser amounts of gramma. Sage and rabbit brush are fairly abundant and cane cactus and prickly pear are locally common. The trees include scattered piñon and juniper with cottonwoods and willows present along the Rio Grande. The Pajarito Plateau has a woodland pasture type of cover. Blue gramma is the main grass throughout the plateau and the trees are piñon and juniper to the east and Ponderosa pine to the west. The latter tree is abundant mainly above about 7,000 feet, but along canyons of the plateau, particularly on north slopes, it extends downward as low as 6,200 feet. The slopes of the Sierra de los Valles have a pine-fir forest. Ponderosa pine is abundant from the base of the slopes up to approximately 9,000 feet, and Douglas and White fir are abundant above about 8,000 feet. Spruce is abundant on the highest parts of these slopes and dense groves of aspen occur in places, particularly where forest fires have removed the conifers in times past. The wide valleys that form the floor of the Valles caldera are lush, unforested grasslands with fescues, bunch grass, and some sedges present. Blue grass has been noted locally. The bounding escarpment and the steep-sided interior domes of the caldera have some Ponderosa pine which is commonly conspicuous along the south and east margin of volcanic domes, but these areas are covered mainly by dense forest of spruce and fir that contain numerous groves of aspen.

GEOLOGY

GENERAL SUMMARY

The rocks that crop out in the Los Alamos area are of late Tertiary and Quaternary age, but older rocks crop out in nearby areas. Rocks of Precambrian age are exposed in the Sangre de Cristos to the east, in the Brazos uplift to the north, and in the Sierra Nacimiento area to the west. (See fig. 4.) These Precambrian rocks, consisting of granite, gneiss, schist, and quartzite, have been downfaulted to great depth in the Rio Grande depression beneath Los Alamos where their upper surface may lie below sea level. Resting unconformably on the Precambrian in the Sangre de Cristo Mountains and the Nacimiento area is the Magdalena group of Pennsylvanian age. This group, consisting mostly of limestone with subordinate shale and sandstone, is exposed a few miles west of the Los Alamos area, just beyond the western margin of the Rio Grande depression; hence, at least part of the group probably is present beneath the Los Alamos area. The same may be said of sandstone of the Abo formation of Pennsylvanian (?) and Permian age. Sediments ranging in age from late Permian through Cretaceous and occurring in the Nacimiento area and around the northwestern part of the Jemez Mountains probably are not present beneath the area. They probably were removed by erosion prior to mid- Tertiary time. However, there is reason to believe that some early

Tertiary sediments and possibly some early Tertiary igneous rocks occur beneath the Santa Fe group in the Los Alamos area.

The late Tertiary and Quaternary rocks that crop out in the Los Alamos area are volcanic and sedimentary rocks associated with the Rio Grande depression, an extensive fault trough which originated in mid-Tertiary time and along which there has been intermittent faulting ever since. For the most part the area lies on the eastern flank of the volcanic rocks of the Jemez Mountains, which stand athwart and which were erupted from feeders within the fault zone at the western boundary of the Rio Grande depression. The western edge of the Los Alamos area is near the center of the collapsed interior of the volcanic rocks and from there the area stretches eastward across a segment of the interior mass of flows and an outer apron of tuff onto a group of sedimentary and volcanic rocks that accumulated within the west-central part of the Rio Grande depression.

The rocks of the Jemez Mountains cover the greater part of the area. This suite of rocks is of late Tertiary and Quaternary age and has been named the Jemez Mountains volcanic series[1]. This series within the area consists of

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[1] Ross, C. S., Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement.

the Tschicoma and Tewa groups. The Tschicoma group forms the interior mass of flows of the volcanic rocks (the Sierra de los Valles) and is represented by two units on the geologic map. The older of the two units is of Pliocene age. This unit occupies the greater part of the rugged slopes of the Sierra de los Valles. It is composed of thick volcanic flows of gray to purplish-gray latite and quartz latite which are characterized by conspicuous phenocrysts of plagioclase feldspar. The younger of the two units is of late Pliocene or early Pleistocene age. This unit crops out in one local area on the Sierra de los Valles, and it is present in the subsurface beneath the Pajarito Plateau in one locality. It is composed of flows of dark gray pyroxene andesite.

The Tewa group is of Pleistocene age. This group includes four map units: the Bandelier tuff, the Cerro Toledo rhyolite, the Cerro Rubio quartz latite, and the Valles rhyolite. The Bandelier tuff, composed of three distinct members, the Guaje, Otowi, and Tshirege members, is a light gray to buff-colored tuff which forms the cap rock of the Pajarito Plateau. This sequence of tuff ranges from about 100 to nearly 1,000 feet thick. It is in part of ash-fall but is largely of ash-flow origin. The Cerro Toledo rhyolite, the Cerro Rubio quartz latite, and the Valles rhyolite are the volcanic domes within and adjacent to the Valles caldera. In addition to the above igneous rocks, there is a thick fill of unnamed lacustrine debris overlain by terrace and alluvial fan deposits in the Valles caldera. These caldera sediments range from Pleistocene to Recent in age.

The suite of rocks that accumulated in the interior of the Rio Grande depression is referred to the Santa Fe group. This group includes three main units: an undifferentiated sequence, the Puye conglomerate, and the basaltic rocks of Chino Mesa. The undifferentiated unit is a sequence of salmon-colored sediments that crop out between the Sangre de Cristo Mountains and the Pajarito Plateau. These sediments are arkosic sandstone and siltstone with some thin beds of pinkish-colored clay. Interbedded basalt occurs locally. The clastic fragments composing the sediments were derived largely from the Sangre de Cristo fault block to the east, but some fragments, present mainly in the subsurface in the area, were derived from the latitic flows of the Tschicoma group. The thickness of the unit is unknown. Wells drilled to a depth of 2,000 feet did not reach its base. The entire unit is of Miocene and Pliocene age, but the portion that is present in the Los Alamos area is believed to represent only the Pliocene part of the sequence.

The Puye conglomerate is exposed along the Puye escarpment and along White Rock Canyon. The formation consists of two members. The basal member is a channel fill which ranges from a knife edge to about 75 feet thick. This member, the Totavi lentil, is a poorly consolidated conglomerate composed of fragments that were derived from a Precambrian terrane. The upper member is a fanglomerate which ranges from a knife edge to about 600 feet thick. This member is composed of latitic debris derived from the latitic flows of the Tschicoma group. The Puye probably is of late Pliocene age.

The basaltic rocks of Chino Mesa are exposed on Chino Mesa and along White Rock Canyon. This sequence of rocks is more than 1,000 feet in thickness and probably ranges from late Pliocene to Pleistocene in age. The sequence has been separated on a basis of composition and form of extrusion into five unnamed members.

A fourth unnamed sedimentary unit (Old alluvium) of the Santa Fe group is closely associated with one of the members of the basaltic rocks of Chino Mesa.

The Santa Fe group and the Jemez Mountains volcanic series accumulated during the formation of the Rio Grande depression, and the various stratigraphic units of the area are completely interrelated. Figure 5 is a diagrammatic sketch showing the relations of the main map units. It is noteworthy that the units of the Santa Fe group interfinger with each other and that the undifferentiated Santa Fe and Puye conglomerate interfinger with the Tschicoma group.

STRATIGRAPHY

Pliocene and Early Pleistocene (?) Rocks

Santa Fe Group

The main part of the fill of the Española-Santa Fe Valley was originally called the Santa Fe marl by Hayden who referred to the "recent marls and sands which seem to occupy the greater portion of the valley of the Rio Grande above and below Santa Fe" (Hayden, 1873, pp. 166-168). Hayden, although describing materials as coarse as "pudding-stone", used the marl designation for the alluvial material because the view was prevalent at the time that the sediments of all the fault-trough basins of the West were lake deposits. In years that followed, Johnson (1903, pp.313-332) and later workers showed the sediments to be chiefly of alluvial origin, and marl was dropped from the name and formation substituted. As more and more became known of the general character of the sediments of the Rio Grande depression, the name was extended to include the bulk of the sediments of the fault-trough fill. Bryan defined the Santa Fe formation as "the main body of sedimentary deposits of the Rio Grande depression, from the north end of the San Luis Valley [Colorado] to and beyond El Paso..................." (Bryan, 1938, p. 205). It now seems desirable to raise the rank of the unit to that of group, as proposed by Baldwin (1955), and include in it other stratigraphic units which are related to the filling of the Rio Grande depression.

The Santa Fe group of this report includes three main units: (1) an undifferentiated unit, largely arkosic debris derived from the Sangre de Cristo mass; (2) the Puye conglomerate, largely a fanglomerate derived from the Tschicoma group; and (3) the basaltic rocks of Chino Mesa. In addition, the group also includes a local unit of old alluvium.

Undifferentiated Unit

The undifferentiated unit of the Santa Fe group is represented by the body of salmon-colored sediments that crop out from the Sangre de Cristo Mountains to the Pajarito Plateau. The great bulk of the sequence was laid down as coalescing alluvial fans and associated alluvial plain deposits in the Rio Grande depression and is composed mainly of arkosic clastics derived from the Sangre de Cristo block. Hence, in general, the sediments are coarsest near the Sangre de Cristos and become finer westward. The rocks are mainly silty sandstones and sandy siltstones. Conglomerates, usually silty to sandy, are fairly well represented, particularly toward the east side of the depression. Beds of clay are not uncommon, but they are thin and in most cases not more than a few feet thick.

In the Los Alamos area a maximum of about 500 feet of the sequence, representing the uppermost part, is exposed on the surface. An additional 1,500 feet is known from well cuttings. The exposed portion extends northward along White Rock Canyon from near the mouth of the Rito de los Frijoles. As the top of the unit rises northward, exposures extend high on the slopes of the Puye escarpment and westward into the lower reaches of Los Alamos and Guaje Canyons. Within this belt of exposures, good outcrops are more or less discontinuous. They are best in the lower parts of Los Alamos and Guaje Canyons and in the fringe of hills along the Puye escarpment to the north. Talus and landslide debris cover much of the unit in White Rock Canyon and along the edges of basalt-capped mesas. The rocks belong mainly to the easterly derived suite of sediments which occur all the way east to the Sangre de Cristo Mountains. There is, however, some westerly derived material, particularly in the subsurface, and there is some included basalt which also is best developed in the subsurface.

The rocks that may be referred entirely to the easterly derived suite are mainly silty sandstone and sandy siltstone that are poorly to moderately cemented. They range in color from pinkish gray to grayish pink to pinkish buff. Sorting is poor and there are fairly rapid variations in texture, both vertically and horizontally. In the coarsest types, bedding is poorly developed. A faint or irregular stratification is fairly general although some zones show no horizontal bedding. Cross-lamination, however, is fairly common, particularly in some better sorted sandstones, and a lenticular arrangement of coarse sizes in beds of finer material is common. In the finer-grained rocks, the clay, sandy siltstone, and some fine-grained very silty sandstone, horizontal bedding is obvious. At some exposures this bedding is poorly developed, in others it is fairly well developed. Cross-lamination is generally absent. The bedding and the fine-grained character indicate that deposition took place on flat-lying surfaces. It seems probable that these finer-grained rocks were laid down on a flat-lying alluvial plain, beyond the margin of alluvial fan deposition.

The sand of the easterly derived rocks consists mainly of quartz and feldspar. Individual quartz particles are colorless to yellowish to pinkish. The feldspar is mainly pink microcline, but some colorless feldspar, at least some of which is plagioclase and at least some of which is sanidine, has been noted. The sand sizes also commonly contain some yellowish to pinkish chalcedonic silica. Dark minerals are nearly absent from the finer sandstones, but they are present in small quantity in the finer fraction of many of the coarser sandstone. They consist mainly of biotite and hornblende. Some clinopyroxene also has been noted. In the gravel sizes quartz, pink microcline, and granitic rocks are most abundant. Pebbles of volcanic rocks that range from andesite to rhyolite are not uncommon, and some pebbles are composed of quartzite and schist. A few are limestone. Particles of silt and clay size have not been examined. The cement of all these rocks is calcite.

Westerly derived material has been noted on the surface in only one locality. Near the mouth of Ancha Canyon, immediately west of White Rock Canyon, there is a sequence of beds that shows an intermixing of easterly and westerly derived fan elements. This sequence, about 200 feet thick, directly underlies the Totavi lentil of the Puye conglomerate. The westerly derived material consists of gravel and boulders of latitic porphyry derived from rocks of the Tschicoma group. Westerly derived materials are more prominent in the subsurface in Guaje Canyon where they are intermixed with easterly derived materials in conglomerates and conglomeratic sandstones. These westerly materials are most abundant at well G5, the westernmost well in the canyon, and least abundant at well G1, the easternmost well in this canyon. At well G5 pebbles of porphyritic quartz latite and white to pale pink pumice of the same composition are very abundant in the upper 459 feet of the unit, above the highest basalt flow in the well. This latitic debris is identical with rocks of the Tschicoma group which crop out about 2 miles to the west. For an additional 198 feet or to 171 feet below the highest basalt flow in the well, there are additional amount of pebbles of porphyritic rocks that must have been derived from the Tschicoma group. All of these westerly derived materials decrease in amount to the east, and in well G1, two and one-half miles eastward, there is only a small amount although sequences of beds containing pebbles of latitic material are present in the upper 560 feet of the unit. (See fig. 6.)

Basalt flows and breccia are present in the undifferentiated Santa Fe and are most prominent in the subsurface. (See fig. 6.) Well G5 in Guaje Canyon penetrated 346 feet of flows and breccia between the depths of 595 and 1327 or between 468 and 1200 feet below the top of the unit. These basalts thin out and disappear eastward. None is represented in well G2, one and one-half miles east. Two miles eastward, however, 250 feet of basaltic breccia was penetrated in a single sequence in well G1. This sequence, lying between 1465 and 1715 feet below the top of the unit, is believed to be from a nearby buried vent. A single basalt flow is exposed in White Rock Canyon where it lies about 200 feet below the top of the unit. All of these basalts are very much alike. They are very dark gray to almost black where fresh and range to reddish brown where they are brecciated and somewhat altered. All of the specimens examined microscopically show tiny phenocrysts of olivine, more or less completely altered to iddingsite or a combination of iddingsite and a high iron saponite,[1] in a

[1] Ross, C. S., Informal communication.

fine-grained groundmass of calcic plagioclase, clinopyroxene, olivine (?), and magnetite. The coarsest plagioclase is close to An_{70}, but some of the finest-grained material and some of the outer parts of zoned crystals seem close to An_{30}. Xenocrysts of plagioclase that have a "motheaten" appearance are present in the two highest flows penetrated by well C5. These xenocrysts of platioclase are identical with xenocrysts that occur in the latitic flows of the Tschicoma group.

The rocks beneath the undifferentiated unit in the area are a matter of conjecture. In the Abiquiu quadrangle north of Los Alamos the Abiquiu tuff underlies the "Santa Fe formation" of Smith (1938, p. 955). Cabot found the Picuris tuff at a similar position at several places along the complexly faulted east margin of the depression, at the west front of the Sangre de Cristo Mountains (Cabot, 1938, pp. 91-93). The Picuris tuff and the Abiquiu tuff, believed to be correlative, may form an essentially continuous unit at the base of the Santa Fe group in the Rio Grande depression in the latitude of the Los Alamos area. In turn the "Abiquiu-Picuris tuff" is probably separated from the Precambrian in places in the depression by Paleozoic and early Tertiary sediments and by early Tertiary igneous rocks. (See Geology, General Summary, p. 39 .)

Within the Los Alamos area, the upper part of the undifferentiated unit of the Santa Fe group is complexly related to the Puye conglomerate, the basaltic rocks of Chino Mesa, and the Tschicoma group. The Totavi lentil of the Puye conglomerate overlies the undifferentiated unit unconformably along the Puye escarpment and along part of White Rock Canyon. Along part of White Rock Canyon, however, the undifferentiated unit is overlain unconformably by Unit 5 of the basaltic rocks of Chino Mesa. And, two miles south of the northern end of Chino Mesa, the uppermost part of the undifferentiated unit interfingers with Units 4 and 5 of the basaltic rocks of this mesa. Immediately north of this particular area the uppermost part of the undifferentiated unit overlies for a distance of about two miles, the Totavi lentil of the Puye conglomerate. (See pl. 1.) This part of the undifferentiated unit probably is at least a partial time equivalent of the Ancha formation of Baldwin (1955), but because of its identical lithology it cannot be separated from underlying sediments along the north edge of Chino Mesa, beyond the point where the Totavi lentil wedges out. The portion of the undifferentiated unit which contains debris from the Tschicoma group undoubtedly interfingers with flows of the Tschicoma in the subsurface in the western part of the Los Alamos area.

The total thickness of the undifferentiated Santa Fe is unknown. The pilot hole at well G1 in Guaje Canyon was bottomed in the unit at a depth of 2100 feet after penetrating a thickness of 2,025 feet. It may extend a great deal deeper than this.

The first fossils collected from the sediments of the Española-Santa Fe Valley were sent to the Smithsonian Institution by W. F. M. Arny in 1872 (Cope, 1877, p. 24). The vertebrate remains aroused interest, and in the summer of 1873 members of the Wheeler survey party collected a number of specimens from near San Ildefonso, a mile northeast of the Los Alamos area. Cope made a trip to the region in 1874 and collected material representing thirty-one species of vertebrates. The faunal descriptions were published in 1877 (Cope, 1877), when Cope concluded that the fauna [of the sediments of the Española Valley] "more nearly resembles the upper Miocene of Europe than the Pliocene of that continent" (Cope, 1877, p. 364). Osborn gave the age of the same sequence as upper Miocene in 1909 (Osborn, 1909, p. 65) but in 1918 decided that the lower part of the sequence is transitional into the Pliocene and the upper part is lower Pliocene (Osborn, 1918, p. 34). Frick in 1933 stated that "recent investigation indicates that the accumulations of this portion [Española Valley area] of the Rio Grande basin range from the mid-Miocene to Pleistocene. The Pleistocene occurs in remnants of aeolian origin that here and there cap the irregular Pliocene-Miocene surface" (Frick, 1933, p. 549). Still more recent investigations by

Frick apparently indicate that the undifferentiated Santa Fe of the immediate region ranges in age from about middle Miocene to about middle Pliocene (Frick, 1937; Wood, et al, 1941, p. 31).

Puye conglomerate

The name Puye gravel has been used by H. T. U. Smith as a formation name in the explanation of his map of the Abiquiu quadrangle which lies a few miles north of the Los Alamos area (Smith, 1938, p. 937). Smith stated in the text of his paper (p. 949) that the new formation which he had mapped would be described in a forthcoming publication. This description has not appeared,but during the course of the Los Alamos work a prominent conglomerate was traced northward and found to be equivalent to the Puye gravel as mapped by Smith. In this report, however, the name Puye conglomerate[1] is used inasmuch as the formation is sufficiently consolidated to stand in vertical cliffs. The type locality is the Puye escarpment and the deep canyons that breach this escarpment.

[1] Ross, C. S., Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement.

The Puye conglomerate is a formation of very local extent. It occurs only on the east side of the Sierra de los Valles where it lies adjacent to the latitic rocks of the Tschicoma group. The strip occupied by the formation

Table 4.--Logs of wells and test holes.

Well G 4, Guaje Canyon.--Continued

	Depth (feet) From	Depth (feet) To
Undifferentiated unit, Santa Fe group--Cont'd.		
Clay, silty, grayish pink	1,550	1,566
Sandstone, fine-grained, silty and sandy siltstone, grayish pink; with some thin beds of pink clay. The sand is arkosic. <u>Some beds are water-bearing, as follows</u>: 1,575 to 1,580 1,586 to 1,591 1,596 to 1,601 1,616 to 1,621 1,681 to 1,696 1,701 to 1,721 1,806 to 1,811 1,826 to 1,831 1,866 to 1,871 1,920 to 1,926 1,936 to 1,941	1,566	2,002 T.D.

is about 10 miles wide, and in the north-south direction exposures extend over a distance of about 15 miles, from the latitude of Espanola southward into the Los Alamos area. South of its exposures it probably exists in the subsurface for a number of miles, although here its east-west extent probably is fairly narrow. South of Los Alamos Canyon the deposition was restricted on the east by lower units of the basaltic rocks of Chino Mesa.

The Puye conglomerate has been divided into two sub-units. A thin basal member is a sandy conglomerate composed of fragments that were derived largely from rocks of Precambrian age. This member, herein named the Totavi lentil, is a broad channel fill. The thick overlying member is a fanglomerate composed of fragments derived from the latitic rocks of the Tschicoma group, but it also includes some basalt flows, water-washed pumice, tuff, and some laharic (mud flow) beds.

Totavi lentil. - - The Totavi lentil [1] is named for the community of Totavi in the eastern part of the area where this part of the formation is excavated for concrete aggregate. The lentil ranges from a knife edge to about 75 feet thick and is a poorly consolidated conglomerate composed of material ranging from fine sand to boulders over one foot

[1] Ross, C. S., Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement.

in diameter. The sand, composed chiefly of quartz and microcline, occurs as lenses and as an interstitial filling between the larger sizes. The gravel and boulders are mainly quartzite, granite, and pegmatitic rocks derived from Precambrian sources, to the north and east. Some fragments are volcanic rocks that are for the most part foreign to the area, and only a few boulders are composed of rocks from the Tschicoma group.

Known exposures of the Totavi lentil extend from several miles north of the Los Alamos area southward to the junction of White Rock and Ancha Canyons in the southeastern part of the area. Good exposures are essentially continuous along the Puye escarpment and in Los Alamos and Guaje Canyons where the lentil occurs along a topographic break between relatively steep slopes formed on the underlying undifferentiated Santa Fe and the vertical cliffs formed by the overlying cemented part of the Puye conglomerate. In the west wall of White Rock Canyon the lentil is continuous, though poorly exposed, to immediately south of Ancha Canyon where it interfingers with basalt and sediments of the lowest unit (TQb_5) of the basalts of Chino Mesa. Beyond this point it could not be separated in mapping from enclosing basalt flows. On the east side of the Rio Grande the lentil has a very limited extent, but it is represented there by thin wedges that pinch out eastward.

In the subsurface west of the outcrop areas the lentil was recognized in several wells and test holes. It occurs in four wells in Guaje Canyon but pinches out between wells G4 and G5 in this canyon. It also is present in well L4 in Los Alamos Canyon and in test holes T1, T2, and T3 farther west in Los Alamos and Pueblo Canyons. In hole H19 in Los Alamos Canyon it is interbedded between two quartz latite flows of the Tschicoma group.

The Totavi lentil lies unconformably on the undifferentiated unit of the Santa Fe group. In places the relation is one of disconformity and in other places a slight angular unconformity may be noted. In the northeastern part of the area the lentil is overlain conformably by the main body of Puye conglomerate. At the northwest tip of Chino Mesa it is overlain conformably by arkosic sediments of the undifferentiated Santa Fe. In White Rock Canyon it is overlain by and interfingers with the basaltic rocks of Chino Mesa. For the most part it is overlain conformably by Unit 5 of these basalts, but south of Ancha Canyon it interfingers with this unit, and in places the lentil is overlain conformably by Unit 4 of the basaltic rocks of Chino Mesa. To the west, in the subsurface, the lentil interfingers with quartz latite flows of the Tschicoma group as shown by the log of hole H19 in Los Alamos Canyon.

Fanglomerate member. - - The main body of the Puye- the fanglomerate member - is composed of debris that has been washed eastward from rocks of the Tschicoma group. In the Los Alamos area exposures of this member extend from a point just southwest of Otowi bridge northwestward along canyons incised in the Pajarito Plateau and northward along the Puye escarpment. Here the member stands in grayish buff colored cliffs which have been intricately fluted by erosion.

Light gray pumice beds ranging from a thin film to a few feet thick have been noted at several localities on the surface, and such beds are very well developed in the fanglomerate in two test holes. There is 90 feet of pumice in the lower part of the unit in test hole T3 in Los Alamos Canyon and 320 feet of pumice lies directly on top of the Totavi lentil in test hole T2 in Pueblo Canyon. These pumice beds are composed of angular to subangular fragments as much as two inches across. Locally they contain abundant fragments of porphyritic latite. Ash-size material commonly fills the interstices. The pumice is latitic and tiny phenocrysts of biotite and plagioclase are common. Tiny hornblende and pyroxene phenocrysts have been noted also. For the most part these beds seem to be water-washed, but some show well developed horizontal bedding, and these may be of ashfall origin. At the eastern margin of the unit, along the Puye escarpment, there are commonly a few thin beds of very fine-grained white tuff. These beds, ranging from about 1 foot to 3 feet thick, rest directly on the Totavi lentil and represent water-laid ash. Other thin beds of tuffaceous material have also been noted at this stratigraphic position at places near the eastern margin of the fanglomerate member. Also represented at some exposures are beds in which large isolated boulders occur in a matrix of sandy silt or silty sand. Beds of this character probably represent laharic-type material.

Most of the fanglomerate member is silty, sandy conglomerate in which two types of beds commonly can be recognized. These alternating beds, differing from each other only in the relative abundance of fines, grade into each other in places and small lenses or tongues of the one occur in the other. In one type of bed silt and sand sizes are a relatively minor constituent, occurring mainly in the interstices between larger fragments. In the other there is a high proportion of sand and silt and these grain sizes commonly predominate over gravel and boulders. Sorting is more or less chaotic in both types of beds. Near the western margin of the member, where it is coarsest, boulders and angular blocks as large as five feet across occur in a matrix that ranges downward to silt size. Ten miles eastward, at the eastern margin, where the member is finest, gravel, sand, and silt are intimately associated. Bedding is poorly developed throughout the member, but a layering that dips one or two degrees eastward can be seen at most localities.

All of the detrital fragments are latitic. The pebbles, cobbles, and boulders are composed of gray to purplish gray to reddish quartz latite and latite. Both types of fragments have a very conspicuous porphritic habit. Phenocrysts of plagioclase, ranging to more than one-half inch long, form some 25 percent of the rocks. Other phenocrysts, much less conspicuous, are augite, biotite, and hornblende. The quartz latite fragments also contain small phenocrysts of quartz. The sand is composed of fragments of these rocks and their phenocrysts. The silt is latitic debris that is commonly partially glassy to glassy.

Flows of basalt occur in the fanglomerate in the subsurface. The flows between 176 and 255 feet in test hole T1 in Pueblo Canyon and those between 266 and 388 feet in test hole T3 in Los Alamos Canyon are medium gray to dark gray in their finer grained portions. Thin sections show small phenocrysts of plagioclase and tiny phenocrysts of olivine and clinopyroxene in a fine-to medium-grained groundmass of semi-felted plagioclase, clinopyroxene, olivine (?), and magnetite. These flows are identical with some of those of Unit 4 of the basaltic rocks of Chino Mesa and are so correlated. The basalt between 410 and 510 feet in test hole T1 is similar to those described above and is tentatively correlated with the same unit.

The upper surface of the Puye is an erosion surface, hence the original thickness of the fanglomerate member cannot be determined. As it now exists, the thickest known section is 637 feet in test hole T2 in Pueblo Canyon. It is thinnest along the east edge of the Pajarito Plateau where about 200 to 250 feet of the unit commonly is present, but it thins to a knife edge just southwest of Otowi bridge where it abuts against basalt of Unit 4 of the basaltic rocks of Chino Mesa.

The fanglomerate member rests conformably on the Totavi lentil and along its eastern and western margins relations indicate that the fanglomerate is contemporaneous in age with parts of the Tschicoma group and the basaltic rocks of Chino Mesa. Ross and Smith ✓ have noted that it interfingers with the latitic flows of the eastern margin of the Tschicoma, and in hole H19 in Los Alamos Canyon it is overlain by flows of pyroxene andesite of the Tschicoma group. Along White Rock Canyon the interfingering of the Totavi lentil with the lowest flows of Chino Mesa (TQb5) indicates that the immediately overlying basalt of this unit is equivalent in age to the lower part of the fanglomerate. The occurrence within the fanglomerate of basalt that is identical in appearance and mineralogy with some of the flows of Unit 4 of the basalt of Chino Mesa indicates contemporaneous accumulation of this basalt unit

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✓ Ross, C. S., and Smith, R. L., Informal communication

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with higher parts of the fanglomerate. Rocks that overlie the Puye disconformably include: (1) Units 2 and 3 of the basaltic rocks of Chino Mesa, (2) the old alluvium, and (3) the Bandelier tuff.

Although the age of the Puye conglomerate has not been established it is believed to be late Pliocene. Fossils found immediately above the Totavi lentil have not been studied.

Basaltic Rocks of Chino Mesa

The rocks of Chino Mesa consist of a thick sequence of basaltic to andesitic rocks with minor amounts of included sediments that form Chino Mesa and cap some outlying mesas and buttes to the north. The rocks belong to the interior of the Rio Grande depression, and only the northern and western extensions are present in the Los Alamos area. Here outcrops occur on mesas and in the walls of White Rock Canyon. In order to determine the relations of various parts of the unit to the Puye conglomerate, five sub-units were separated in the area.

Unit 5, the oldest of the sub-units, consists of basalt, basaltic tuff, and locally some associated sediments. The individual basalt flows are generally thin and commonly not over 25 feet thick, and they generally show well-developed columnar jointing. They range in color from dark gray to almost black and there commonly is a faint greenish hue. All are porphyritic. Small phenocrysts of olivine, ranging to almost one-quarter inch across are present in all specimens though in many places they are highly altered. The alteration is variable. In some specimens it is a mixture of saponite and celadonite [1]; in others it is iddingsite. A number of specimens contain small xenocrysts of quartz surrounded by a rim of radiating crystals of augite. The groundmass is sodic labradorite, clinopyroxene that probably is pigeonite, some olivine that commonly shows the same alteration as the phenocrysts, and some magnetite. The basaltic tuffs of the unit are very distinctive and in the southern part of the exposure belt they are very conspicuous. These tuffs are very thinly bedded and weather to a drab color. They grade to tuff breccia in places, and they commonly contain some pebbles that have been derived from Precambrian sources and some that have been derived from the Tschicoma group. The associated sediments are present near the north end of the unit. At the mouth of Mortandad Canyon they consist of arkosic sandstones and conglomerates that contain interbedded basalt.

[1] Smith, R. L., Informal communication.

Unit 4, conformably overlying Unit 5, is the main cliff-former along White Rock Canyon. It consists of flows of both basalt and basaltic andesite. Locally there is a little basaltic tuff and thin sandstone beds. The flows tend to be more massive than those of Unit 5. In places individual flows range to over 50 feet thick. They range from gray to dark gray and are generally lighter in color than those of the underlying unit. Some specimens show small or tiny phenocrysts of olivine only; others show both olivine and pyroxene; still others olivine, phyroxene and plagioclase; and still others show small phenocrysts of pyroxene only. The groundmass is composed of plagioclase, clinopyroxene, and some magnetite. Some specimens may contain a little olivine. The plagioclase ranges from sodic labradorite to calcic andesine.

Unit 3 consists of massive, steep sided flows of dark gray basalt that commonly have a thick zone of breccia at their base. These flows apparently overlie Unit 4 disconformably, and sediments associated with the flows overlie the Puye conglomerate disconformably. The best and most accessible exposure of the unit is along Highway 4 at the top of the hill west of Totavi. Here the upper part of a flow pinches out in sediments of post-Puye age (old alluvium). The rocks of the unit contain large to small phenocrysts of olivine, and some specimens contain tiny phenocrysts of plagioclase. The groundmass is composed of plagioclase and clinopyroxene with a little olivine and magnetite.

Unit 2 consists of two flows of basalt that originated on the east side of Chino Mesa and flowed northwestward into the Los Alamos area. At Mesita Mesa these flows and some underlying basaltic tuff overlie the undifferentiated unit of the Santa Fe group unconformably. Farther west, toward Totavi, they unconformably overlie the Puye conglomerate. Just east of Totavi the upper of the two flows ends. The lower one continues westward for a short distance and then abuts against a massive flow of Unit 3. The two flows are identical in character. They are dark gray and contain conspicuous phenocrysts of olivine, some of which have a thin rim of iddingsite. A few xenocrysts of quartz, generally surrounded by radiating crystals of augite, have been noted. The groundmass is very sodic labradorite, clinopyroxene, olivine, and magnetite, given in the order of abundance.

Unit 1 consists of late cinder cones, local flows, and a small dome of basalt. They overlie unconformably all the rocks with which they are in contact. The unconformable relation to Unit 2, the next older unit, can best be seen at the north end of Chino Mesa. Where they are not oxidized the rocks are almost black, but in the cinder cones where they are highly vesicular and oxidized they are brownish red. They are inconspicuously porphyritic and in some hand specimens phenocrysts cannot be noted. Thin sections show tiny phenocrysts of olivine, possibly a few of pyroxene, and a few of labradorite. The fine-grained to glassy groundmass shows plagioclase microlites and pyroxene with a little olivine and magnetite.

The oldest units of the basaltic rocks of Chino Mesa probably are late Pliocene and the youngest are almost certainly Pleistocene. Unit 5 conformably overlies and interfingers with the Totavi lentil of the Puye conglomerate. Therefore much of Unit 5 is contemporaneous with the lowest part of the fanglomerate portion of the Puye. Unit 4 also is contemporaneous with the fanglomeratic Puye as flows of this unit occur within the fanglomeratic Puye. (See logs of holes T1 and T2.) Units 4 and 5 interfinger with the uppermost part of the undifferentiated unit of the Santa Fe at a point about two miles south of the northern tip of Chino Mesa. The three youngest units of basalt are of post-Puye age. Unit 3 may be seen to interfinger with sediments (old alluvium) that lie disconformably on the Puye near the top of the hill west of Totavi. Unit 2 probably closely followed Unit 3, but evidence is not sufficient to bear this out. Unit 1 is almost surely of Pleistocene age. It rests unconformably on Unit 2, and beyond the Los Alamos area it is associated with a low pediment or terrace along the Rio Grande.

Old Alluvium

Near the east edge of the Pajarito Plateau some high-level alluvium rests unconformably on the Puye conglomerate and is associated with flows of Unit 3 of the basaltic rocks of Chino Mesa. This alluvium consists of clay, sand, and gravel and locally includes a minor amount of basaltic tuff. The best development as well as the best exposure of the unit is along Highway 4 near the top of the hill west of Totavi. At this exposure there are four sets of beds. The lowest is a one-foot bed of basaltic tuff. This is overlain by 20 feet of brownish gray, thinly laminated clay which weathers to a dull brown. Next is about 50 feet of silty sand and gravel that ranges from buff to brownish yellow. This is overlain by about 25 feet of gray, thinly laminated clay that weathers to a dirty grayish green. Northward, beyond Guaje Canyon, only the sand and gravel and the overlying clay have been noted. Southward, some of the beds have been noted in Mortandad Canyon and at the northwest tip of Chino Mesa.

This alluvium was deposited on a pediment surface cut on the Puye conglomerate, but at places it abuts against the edge of a higher, partially dissected pediment also cut on the Puye. The deposition occurred behind basalt of Unit 3 of the basaltic rocks of Chino Mesa during the time these flows accumulated. At the exposure along Highway 4 west of Totavi the alluvium is in contact with a steep-sided flow of basalt which has a tongue that pinches out within the alluvium. The age of the material is believed to be either late Pliocene or Pleistocene.

Tschicoma Group

The Tschicoma group includes all of the rocks of the complex interior mass of the Jemez Mountains volcanic series.[1]

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[1] Ross, C. S., Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement.

The type locality is Tschicoma peak, about 5 miles north of the Los Alamos area. In the Los Alamos area rocks belonging to the group lie between the Pajarito Plateau and the Valles caldera. They occupy the greater part of the steep rugged slopes to the west of the plateau where their exposure belt is a segment of the Sierra de los Valles. Two map units have been separated within the belt. One, covering hearly all of the belt, consists of conspicuously porphyritic flows of latit and quartz latite. The other, occupying a very local area on the surface, consists of rather inconspicuously porphyritic pyroxene andesite. This unit is best developed in the sub-surface.

The latite and quartz latite unit occurs in flows that range from about 200 to about 400 feet thick, and the rocks are mainly gray to purplish gray, but in places they range to reddish brown. Both rock types carry abundant phenocrysts of plagioclase which tend to be slightly larger and more abundant in the quartz latites where they range to over one-half inch in greatest dimension and commonly compose over 25 percent of the volume of the rock.

In general the quartz latite flows are present to the north of Los Alamos Canyon and the Quemazon fork of this canyon where they form distinctive hummocky slopes. Individual exposures generally show pronounced jointing and in places the flows grade to blocky breccia. Some exposures show flow tops that grade to pumiceous glass. The abundant plagioclase phenocrysts actually are in large part xenocrysts, and obviously were not in equilibrium with the groundmass in which they occur. These xenocrysts have a motheaten appearance caused by tiny areas of included glass. They are embayed by groundmass material, and some are resorbed to the extent that only ghost-like remnants are recognizable. The plagioclase phenocrysts that belong to the rock are fresh in appearance and show good albite twinning. Other phenocrysts present are small. They consist of quartz, biotite, hornblende, and augite. The quartz is sub-round and embayed. The biotite and hornblende are in various stages of resorption. The groundmass of these rocks is composed of plagioclase, orthoclase, augite, a little fine magnetite, and varying amounts of glass.

The latite flows are present to the south of Los Alamos Canyon and they appear to have lapped against the quartz latite flows near the axis of this canyon. In hole H16 at the head of the Quemazon fork of the canyon latite overlies quartz latite with the former present from 627 to 890 feet and the latter present from 890 to the total depth of 1,269 feet.

Southward, the latite forms somewhat smoother slopes than the quartz latite to the north, and the flows appear to have been more regular and less pasty than those which gave rise to the quartz latite. The rocks are, however, very similar to the quartz latite and presumably belong to the same period of eruptions. They contain large phenocrysts of plagioclase that are in general identical with those of the quartz latite, including even the foreign variety. The small mafic phenocrysts are the same and include augite and more or less resorbed biotite and hornblende. The augite is more abundant than in the quartz latite. Unlike the quartz latite, quartz phenocrysts are absent. The groundmass of plagioclase, orthoclase, augite, some fine magnetite, and in places some glass is similar to that of the quartz latite but there appears to be less orthoclase in the groundmass of the latite.

The pyroxene andesite map unit is exposed in a small area north of Los Alamos Canyon where it lies disconformably on a flow of quartz latite. In the subsurface in hole H19 it is represented by two or three flows having an aggregate thickness of 347 feet. The rocks of this unit are inconspicuously porphyritic and range from gray to dark gray in color. Locally they show a few scattered phenocrysts of plagioclase ranging to about one-quarter inch across but for the most part the phenocrysts are to be noted only by close examination and some specimens are almost non-porphyriti

The phenocrysts consist of zoned plagioclase and pyroxene, with the pyroxene including both augite and hyperathene. One specimen examined showed some foreign brown biotite. The groundmass is composed of felted plagioclase, pyroxene, and some magnetite.

Through several criteria it is possible to relate the rocks of the Tschicoma group to the undifferentiated unit of the Santa Fe group and to the Puye conglomerate. Debris from the quartz latite flows is present in the upper part of the undifferentiated Santa Fe. This debris is abundant in the subsurface in the upper 400 feet of the formation in Guaje Canyon. In wells G4 and G5 it is confined to that portion of the formation lying above the highest basalt flow in these wells. (See fig. 6.) In hole H19 in Los Alamos Canyon the Totavi lentil of the Puye conglomerate is interbedded in the upper part of the quartz latite sequence. And both the quartz latite and latite furnished debris to the main body of Puye conglomerate in the Los Alamos area. In turn the Puye conglomerate is overlain in hole H19 by flows of the pyroxene andesite unit of the Tschicoma group.

The relation of the Tschicoma group to the upper part of the undifferentiated Santa Fe and to the Puye conglomerate indicates that the Tschicoma group is of Pliocene and possibly early Pleistocene instead of Miocene age as was assumed by early workers (Darton, 1928; Bryan, 1938). In earlier work it was assumed that the Tschicoma group was correlative with the main body of volcanic rocks in the San Juan region of Colorado. However, the upper limit of the undifferentiated unit of the Santa Fe group is apparently close to mid-Pliocene age (Frick, 1937), and debris from the Tschicoma group does not extend greatly below this limit in Guaje Canyon. In well G5, which is closest to the main body of the Tschicoma group, debris from the latite and quartz latite is not present below the top of the highest basalt flow which is 468 feet below the top of the unit. (See fig. 6.) Below this basalt there is some debris from older rocks of the Tschicoma group for an additional 200 feet. At greater depth the only possible evidence of the existence of rocks of the Jemez Mountains volcanic series is the thick basalt sequence in the well. This thick basalt sequence may represent the beginnings of the volcanic series. The pyroxene andesite unit of the Tschicoma group, overlying the Puye conglomerate, probably represents some of the youngest flows of the group. These youngest flows may be of early Pleistocene age.

Pleistocene and Recent Rocks

Tewa Group

The name Tewa group[1] is used herein for the late

[1] Ross, C. S., Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement.

rhyolite and a local unit of quartz latite that constitute the latest eruptions of the Jemez Mountains volcano. As no single physiographic feature is present from which to take a name for the diverse group, Tewa has been chosen inasmuch as a large part of the area in which the group occurs is known as the country of the ancient Tewa Indian tribe. Formations belonging to the group within the Los Alamos area are the Bandelier tuff, Cerro Toledo rhyolite, Cerro Rubio quartz latite, and Valles rhyolite.

Bandelier tuff

The Bandelier tuff was named by H. T. U. Smith (Smith, 1938, p. 959) who first recognized the formation as a distinct unit and who mapped its northern extension in the Abiquiu quadrangle. The name was taken from the Bandelier National Monument where the tuff is typically developed. In the Los Alamos area the unit is most prominent along the east-west canyons of the Pajarito Plateau where it forms spectacular cliffs. In these cliffs three distinct sub-units are obvious. The lowest sub-unit is white lump pumice that is well developed in the vicinity of Guaje Canyon and is here named the Guaje member.[1] Above this is a sub-unit of pumiceous tuff

[1] Ross, C. S., Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement.

breccia that tends to stand in steep slopes and in many places forms the lower part of the walls of the canyons of the Pajarito

Plate 10.--Guaje member of Bandelier tuff lying disconformably on basalt. At top of hill east of Totavi.

Plate 11.--Otowi and Tshirege members of Bandelier tuff showing the disconformity between the two units. Pueblo Canyon.

Plateau. This is the Otowi member.[1] It is named from

[1] Ross, C. S., Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement

typical exposures in the Otowi section of the Bandelier Monument. The third and highest sub-unit is a welded tuff that forms vertical cliffs along the canyons of the plateau and in places extends high on the flanks of the Sierra de los Valles. It also occurs in places in the collapsed area of the Jemez volcanic series. This has been named the Tshirege member[1]

[1] Ross, C. S. Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement.

from the Tshirege ruins, a centrally located ruin on the Pajarito Plateau.

The Guaje member rests disconformably on all the older rocks with which it is in contact. This member is a white lump pumice or lapilli tuff that ranges from a knife edge to nearly 60 feet thick in the area. It is thinnest to the east and south where it pinches out on higher parts of the basalts of Chino Mesa, and it thickens to the north and west. The thickest known section is in hole H19 in Los Alamos Canyon where it is 57 feet thick. The best exposures are along Highway 4 in sec. 21, T. 19 N., R. 7 E., and just north of well G3 in Guaje Canyon where the pumice is being mined. The member is composed of unconsolidated pumice which is generally massive except for an upper 5 to 10 feet where good ash-fall bedding is displayed. The sizes of fragments range from ash to lumps 2 inches in diameter. The finest sizes are toward the top of the member. Present in individual pumice fragments are tiny phenocrysts of sanidine and quartz.

The Otowi member represents a single thick pumice flow with a small amount of ash-fall pumice and water-washed debris present in places at the top. This member rests conformably on the Guaje member where the latter is present. Elsewhere it rests disconformably on older rocks. The exposure belt is essentially limited to the Pajarito Plateau. Through the exposure belt the member commonly forms a steep slope below the overlying Tshirege member. Where this slope is without vegetation the member is displayed in chalky light gray or light buff color and in places the slope is studded with cone-shaped erosion remnants, sometimes called "tent rocks". The thickness of the Otowi member ranges from a knife edge to more than 200 feet. It is thinnest in the southeastern part of the area where it pinches out over some of the highest areas of basalt. It is thickest near the Los Alamos townsite, and in hole H19 in Los Alamos Canyon it is 215 feet thick.

This thick pumice flow is a massive aggregate of poorly sorted pumice fragments with some fine pumiceous glass. The aggregate is somewhat indurated though essentially unconsolidated, and the fragments range from silt size to lumps three inches across. Individual fragments are unaltered or essentially unaltered glass that is pale buff in color. The fragments contain phenocrysts of sanidine and quartz and a few tiny grains of magnetite. Some fragments carry a trace of biotite and hornblende. Included as foreign material in the aggregate are a few fragments of rocks derived from the Tschicoma group.

These fragments are mainly latitic rocks but some are light gray rhyolite. They are not evenly distributed through the rock, and where most abundant they compose less than five percent of the outcrop area. In places at the top of the member are a few thin beds of ash-fall pumice. Also present in places in this stratigraphic position is some water-washed pumice that includes boulders of latitic rocks derived from the Tschicoma group.

The Tshirege member is a welded tuff that represents two or three ash-flow eruptions and in places the unit includes a few thin beds of ash-fall pumice at both the base and top. This member forms the most conspicuous part of the Pajarito Plateau on which it stands in long finger-like mesas bounded by vertical cliffs that are generally weathered to tan or orange-brown color. Locally it extends high on the flanks of the Sierra de los Valles, and in places it is present in the caldera area of the Jemez Mountains volcanic series. It rests unconformably on all the rocks with which it is in contact, but a minor disconformity at the top of the Otowi member represents a relatively short time break. The thickness ranges from about 100 to 200 feet near the eastern margin of the area to nearly 1000 feet at the head of the Rito de los Frijoles in the southwestern part of the area.

The character of the Tshirege member varies. Over most of the Pajarito Plateau the rock is porous and friable and ranges in color from buff to pale gray. More intensely welded material near the west margin of the plateau and on the flanks of the Sierra de los Valles is commonly nonporous and gray to purplish gray. More or less irregular jointing is fairly general. Locally there is well-developed columnar jointing. Nearly horizontal planes seen in the cliffs are in part boundaries between successive ash flows rather than bedding planes. Individual hand specimens show small fragments of recrystallized pumice and numerous small crystals and crystal fragments of sanidine and quartz in a typical welded tuff matrix. Dark minerals are nearly absent though traces of crystal fragments of biotite, hornblende, and pyroxene have been noted. Thin sections show that the matrix is composed of recrystallized shards and a little fine-grained magnetite.

The available evidence, mainly physiographic, indicates that the age of the Bandelier tuff is Pleistocene. At the time of the Bandelier eruptions, the rocks of the Tschicoma group (Pliocene and possibly early Pleistocene) had been deeply eroded. Deep canyons cut in the Tschicoma were filled by the Bandelier. This is also true of Units 4 and 5 of the rocks of Chino Mesa. A deep canyon, previously occupied by the Rio Grande, had been cut in these units a short distance west of White Rock Canyon. This abandoned canyon is now filled with tuff and is well exposed in the Rito de los Frijoles. Another channel fill is present in the east wall of White Rock Canyon. Here the base of the Bandelier fill in the abandoned channel is only 200 feet above the present level of the Rio Grande. And, over much of the Pajarito Plateau the original upper surface of the Bandelier is still preserved.

Cerro Toledo rhyolite

The name Cerro Toledo rhyolite[1] is applied to rocks

[1] Ross, C. S., Smith, R. L., Informal communication.

which form a group of domes that occur both north and south of the Valles caldera. The name was taken from Cerro Toledo, a peak in the northwestern part of the area. This rhyolite crops out both in the northwestern part of the area, between the Rito de los Indios and the Valle de los Posos, and in the southwestern part of the area, just south of the Valle Grande. In both places the rocks of the unit crop out on high, forested peaks.

The northern exposures are a part of a complex group of domes within an unnamed caldera,[1] an earlier collapsed portion

[1] Ross, C. S., and Smith, R. L., Informal communication

of the Jemez Mountains volcanic series. Just beyond the south margin of these exposures the rhyolite is downfaulted into the subsurface at the north edge of the Valles caldera. The exposures south of the Valle Grande are a part of a composite dome whose northward extension has been downfaulted into the subsurface in the southern part of the Valles caldera.

Most specimens of the unit show a noticeable banding and are generally light gray in color. Thin sections show tiny phenocrysts of sanidine, quartz, and traces of more or less resorbed hornblende and biotite in a fine-grained groundmass that is commonly microspherulitic and composed of sanidine and silica.

The domes were extruded prior to the eruptions of the Tshirege member of the Bandelier tuff which unconformably overlies the domes immediately north of the Valle Toledo. They probably were extruded following[1] the eruptions of

[1] Ross, C. S. and Smith, R. L., Informal communication.

the Otowi member of the Bandelier tuff, in Pleistocene time.

Cerro Rubio quartz latite

The Cerro Rubio quartz latite has been named by Ross and Smith[1] from exposures in the northern part of the

[1] Ross, C. S., and Smith, R. L., Informal communication.

Los Alamos area where the unit crops out in two conical domes immediately north of the Valle de los Posos. Both domes, Cerro Rubio on the south and the unnamed peak immediately north, are just beyond the margin of the Valles caldera.

The rocks are light gray grading to darker gray in somewhat glassy specimens. At Cerro Rubio they weather to a grayish red. Specimens show tiny phenocrysts of plagioclase, hypersthene, and more or less resorbed hornblende and biotite in a fine-grained groundmass of plagioclase, sanidine, and silica. At the west side of Cerro Rubio the unit intrudes the Cerro Toledo rhyolite. At the east side of the dome the Tshirege member of the Bandelier tuff lies unconformably against the quartz latite.

Valles rhyolite

The Valles rhyolite[1] forms the domes within the

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[1] Ross, C. S., Smith, R. L., and Griggs, R. L., Nomenclature by mutual agreement.

Valles caldera. These domes, with a fairly heavy forest cover, stand above the present-day grass-covered floor of the caldera and they range from relatively small hills to large mountainous masses. The smaller domes are sub-round in plan and sub-conical in cross section. The larger ones are composite masses of several domes and are more irregular in plan and cross section, but they have a more or less domal upper surface. The bases of these domes are covered by later sediments that partially fill the Valles caldera.

Where there has been a minimum of erosion the outer parts of the domes are a jumble of blocky pumice and pumiceous glass which ranges from white to light gray to pale pink. Toward the interior of this outer zone are local areas of obsidian. Farther inward the glassy crust gives way to slightly porous light gray rhyolite that is slightly glassy and commonly spherulitic. In more deeply eroded parts of the domes the rocks are light gray, fine-grained rhyolite. Thin sections of essentially all the rocks show abundant small phenocrysts of sanidine and quartz. Some sections show tiny phenocrysts of hornblende and/or biotite, and a few sections carry a trace of plagioclase phenocrysts. The groundmass of the non-glassy rocks is sanidine and silica.

The Valles rhyolite is the youngest igneous rock of the area. The domes were extruded in the Valles caldera following the explosive eruption of the Tshirege member of the Bandelier tuff and following the collapse of the Valles caldera. Their time of extrusion was Pleistocene.

Caldera fill

For some time following the collapse of the Valles caldera a lake occupied the steep-walled depression, and in this lake a sedimentary fill accumulated. The fill is poorly exposed and its character is known mainly from test holes drilled in the Valles caldera during the summer of 1949.

(See figs. 8 - 10.) It consists of gravel, clayey silt to silty clay, and may include some pyroclastic debris.

Surface exposures of the caldera fill are poor as this fill is almost completely covered by later deposits of alluvial fan and terrace material. In the Valle Toledo clayey silt crops out in several places along the edges of terraces that are present on both sides of the valley. On the south side of the valley the contact of the silt with overlying terrace material is marked in the edge of the terrace by a slight declivity along which several wet-weather seeps occur. The best exposure in the valley is a few hundred feet south of hole H4 where about 10 feet of clayey silt may be seen. The beds are olive colored, weathering olive buff to light gray. The bedding ranges from fairly massive to thinly laminated. Some material contains numerous diatoms. At another exposure the silt ranges from clayey to sandy and contains pebbles of pumiceous glass and rhyolite up to 1 inch in diameter. In the Valle Grande two very small exposures of clayey silt containing pebbles of rhyolite have been noted. Here the fill is essentially covered completely by later deposits of alluvial fan and terrace material. Along the east side of the caldera there is a complete cover of alluvial fan deposits.

In the subsurface the caldera fill is known from well cuttings from 15 holes that range from 285 to 1,185 feet deep. The cuttings show that the sediments are dominantly gravel, which possibly includes some pyroclastic debris, and less important amounts of silty clay and clayey silt. The gravel, with more or less admixed sand and silt, is composed mainly of pebbles of white to light gray pumice and pumiceous glass which invariably shows tiny phenocrysts of sanidine and quartz. Some pieces show tiny phenocrysts of biotite. Other rock types represented in the pebbles are rhyolite, glass, and porphyritic latite. The rhyolite varies in type but probably the most common variety is light gray, very finely porous, and microspherulitic. Most pieces have tiny phenocrysts of sanidine and quartz. Some show tiny phenocrysts of hornblende. The pebbles of glass are gray to black obsidian, and those of porphyritic latite, which are relatively uncommon, are purplish gray with white phenocrysts of plagioclase.

The range in size of the gravel is probably large. The largest whole pebbles that were washed from the test holes by artesian water discharging at the land surface were about two inches in diameter. However, it is suspected that toward the margins of the rhyolite domes and near the scarp of the caldera particle sizes probably range to large boulders. The admixed sand in the gravel is composed of crystals and crystal fragments of sanidine and quartz and particles of pumiceous glass. Silt sizes that are present in some beds of gravel are fine rhyolitic material. The beds of clayey silt and silty clay which occur in the fill are very characteristic. They range from brownish olive through olive green to olive buff and are composed of fine rhyolitic material and varying amounts of clay. Some of the clay beds contain appreciable amounts of gravel and many contain abundant diatom remains. Several specimens examined microscopically by Ross and Smith[1] showed very fine rhyolitic material and montmorillonite-type clay.

[1] Ross, C. S., and Smith, R. L., Informal communication.

In the Valle Toledo the clayey silt and silty clay beds are interbedded in, and interfinger with, a main body of gravel. (See figs. 8 and 9.) As indicated by exposures and test hole data a single section of clayey beds close to 100 feet thick in the vicinity of hole H4 thins and interfingers with gravel to the east. Clayey beds present at deeper levels in hole H1 disappear eastward. Little data are available as to the extent of clayey material toward the north and south sides of the valley, but the log of hole H5 and ground-water data indicate that some beds extend for considerable distance to the north but pinch out before reaching the caldera wall.

In the Valle Grande a thick body of clayey silt and silty clay overlies a main body of gravel that may include some pyroclastic debris. The logs of holes H7 to H12 and H15 (fig. 10) show that the thick body of clayey material is best developed in the central part of the valley where it is nearly 300 feet thick and that it interfingers with gravel toward the sides and head of the valley. The upper part of the coarse material beneath the clayey body is definitely gravel as worn pieces of pumice and rhyolite were recovered from holes H7 to H12 and H15, but a slight possibility exists that some material, particularly from the deeper part of hole H7 which extended to 1185 feet, may represent pyroclastic debris.

Along the eastern side of the caldera, materials taken from holes H13 and H14 were indefinite. The writer believes that the upper part of the caldera fill in this area is gravel and that this gravel possibly may grade downward into pyroclastics.

The materials composing the caldera fill were derived mainly from the pumiceous crusts of the rhyolite domes that occur within the Valles caldera. The pumice gravel and much of the clayey silt and silty clay are products of these crusts. The partially glassy to fine-grained rhyolite came from slightly deeper portions of these domes and from the interiors of faulted domes on the caldera rim. Latitic pebbles in the fill, present in very minor amount except in the lower part of hole H7 in the Valle Grande, are from the caldera rim.

The accumulation of the coarse materials in the caldera probably was rapid. An abundance of loose material was available in times past. Even today there is in many places an abundance of loose debris on the steep slopes of the domes. Such debris could have been readily carried to the edge of the lake by the melt waters from heavy Pleistocene snows. It also seems possible, perhaps probable, that the lake had formed before the emplacement of some of the domes and that during endogenous growth their expanding and cracking crusts may have contributed debris directly to the water.

The mechanism or mechanisms that carried the gravels out into the centers of the Valle Toledo and particularly the Valle Grande are unknown. At the very beginning of deposition much debris may have readily worked its way down steep under-water slopes to the central part of deep basins. Somewhat later it seems probable that delta-like accumulations built up at the margins of the lake, adjacent to the interior domes and the caldera rim. Much debris may have slumped, possibly under the influence of late minor adjustments in the lower part of the caldera, from the outer parts of those delta-like accumulations and worked outward into deeper water. And in part much pumiceous material may have floated out to deep water and sank after becoming water-logged. Lastly, it is possible that large quantities of gravel may have been deposited at times when the lake was dry. The clayey silts and silty clays are normal lake sediments and are best developed far out from the steep slopes of the caldera. However, the lateral development of thin zones of silt and clay in the Valle Toledo indicates that there were times during the deposition of the fill when little coarse debris was being washed into the depression.

The age of the caldera fill is Pleistocene. Plant spores from the upper 40 feet of sediments in the Valle Grande examined by Paul Sears and Catherine Clisby[1] are believed to have been deposited in the last 25,000 years. If the deposition was relatively rapid, as is believed, then the entire fill probably is late Pleistocene.

[1] Sears, P., Yale University, and Clisby, C., Oberlin College, Informal communication, 1952.

Alluvium

Pleistocene and Recent alluvium is present as terrace and fan deposits in the Valles caldera and as terrace and stream channel deposits along the Rio Grande and some of its tributaries.

There are two sets of terraces in the caldera. The higher set is represented by two small remnants in the south-eastern part of the Valle Toledo, and one small remnant near the head of the Valle Grande occurs just above an altitude of 8,800 feet. These small remnants are capped by a veneer of sand and gravel composed of various types of rhyolitic materials. The remnants and their veneer probably are the remains of a lake terrace. The lower set of terraces is well developed adjacent to the drainage in both the Valle Grande and Valle Toledo. These terraces are related to the streams to which they are adjacent as they slope toward the axes of the streams and they gradually slope to lower elevations downstream. They are capped by a veneer of silt, sand, and gravel composed chiefly of various types of rhyolitic materials that range from about 10 to 30 feet thick.

Extending inward from the steep slopes of the caldera rim and away from the interior rhyolite domes are alluvial fans which extend onto and are later than the low set of terraces. These fans are composed mainly of sand and gravel but contain much silt. These materials have been derived from the bedrock units from which the fans extend. Below the low terraces and adjacent to the streams in the caldera is a narrow band of channel alluvium. This alluvium is composed of clayey to silty sand and gravel made up mainly of rhyolitic debris.

In the eastern part of the Los Alamos area some additional alluvium occurs along the Rio Grande and a number of its tributary canyons. Between the Puye escarpment and the Rio Grande there is a low terrace that slopes to the Rio. It is capped by a veneer of silt, sand, and gravel, probably less than 25 feet thick, that is composed mainly of latitic materials derived from the Puye conglomerate. Immediately adjacent to the Rio and to some of its tributary canyons and arroyos is some channel alluvium composed of a variety of materials. This channel alluvium ranges from a thin film to about 25 feet thick and locally consists of fairly clean sand and gravel but in most places it contains considerable silt.

HISTORICAL GEOLOGY

The rocks of the Los Alamos area are related to the Rio Grande depression, and their history is in large part a history of this depression and its associated volcanism. Pertinent history began with the formation of the Southern Rocky Mountains and post-Cretaceous uplift of the region. The orogenic phases of the mountain building seem to have passed into broad regional uplift and arching before the end of early Tertiary time. By mid-Tertiary time, probably in part as a result of arching and elongation of the earth's crust, the faulting that gave rise to the Rio Grande depression began. As the complex rift valley subsided relative to adjacent highlands, the Santa Fe group accumulated as a fault trough fill. Accompanying the disturbance of uplift and concomitant normal faulting the volcanic rocks of the Los Alamos area were erupted. (See fig. 7.)

In the latitude of Los Alamos the sediments of the Santa Fe group were laid down as coalescing alluvial fans and alluvial plain deposits. For the most part the alluvial debris was deposited by streams and rills passing westward from the Sangre de Cristo Mountains and depositing their loads in the adjacent valley. It is estimated that more than 75 percent of the alluvial debris composing the Santa Fe came from this mountain block, the eastern boundary and the structurally high side of the Rio Grande depression in the vicinity. The explanation for this predominance of easterly materials, largely derived from Precambrian sources, may lie in the structure of the blocks that bound the depression. The Precambrian rocks now stand some 6,500 feet higher in the Sangre de Cristos, where they reach an altitude of 13,000 feet, than at the west side of the depression, where they reach an altitude of only 6,500 feet. If the extra 6,500 feet of rise of the eastern block occurred during the deposition of the valley fill, then it offers an explanation for the dominance of easterly materials in the valley fill. (See fig. 7.)

Evidence that sedimentation accompanied uplift and faulting during the formation of the Rio Grande depression is believed ample. The alternation of alluvial fan and alluvial plain deposits in the latitude of Los Alamos is one line of evidence. At the east side of the depression very coarse and bouldery alluvial fan elements are commonly underlain and overlain by fine-grained, well-bedded alluvial plain deposits. The best explanation is a control of gradients and facies by repeated faulting. Following a stage of faulting and relative uplift of the bounding mountain block, a typical fan would have been built up adjacent to the mountains. As deposition continued, gradients would have become less and less steep as the mountains were eroded and the level of the depression floor was built up. Eventually, thick zones of fine-grained, well bedded materials would encroach eastward and overlap the coarser fan deposit. Repeated faulting would have started a new cycle.

It also seems necessary to invoke some faulting as a means of explaining some structure within the Santa Fe group. In places east of the Los Alamos area truncated beds of the Santa Fe group are overlain by beds showing less dip. The tilting of portions of the unit beneath unconformities can be explained best by faulting in the interior of the depression.

There is still further evidence in the presence of a few narrow downfaulted horsts of Pennsylvanian limestone that occur in places along the east side of the Rio Grande depression. These horsts were dropped into the depression before the thick cover of limestone had been largely eroded from the adjacent mountain block. And lastly, the presence of interbedded basalt in the Santa Fe group indicates that deep-seated faults were open at times during the formation of the depression and the accompanying deposition.

During the later stages of Santa Fe time the Jemez Mountains volcanic series began to accumulate along a fault zone at the west margin of the depression. Possibly the first stages of the development of the volcanic rocks, which are at the western margin of the depression, are marked by the lowest basalts in wells G3 to G5 in the Los Alamos area. And it is only above the highest basalt flow in wells G4 and G5 that unquestionable debris from the latitic flows of the Tschicoma group appears. It is probable that the lowest basalt flows in well G5 mark the first rupture of the earth's crust at the western margin of the Rio Grande depression in this latitude and the sequential development of the Jemez volcanic pile.

As the thick and pasty latite flows of the Tschicoma group were erupted they moved eastward into the fault trough. In the beginning some loose material from the flows was washed eastward where it mixed with easterly derived materials of the Santa Fe group. Slightly later, following some faulting which tilted the Santa Fe, the ancestral Rio Grande appeared. The evidence is in the Totavi lentil of the Puye conglomerate. This lentil, largely channel fill, rests unconformably on the Santa Fe and in places along its west margin interfingers with the latite flows of the Tschicoma group. The overlying main body of the Puye was deposited as an alluvial fan, apparently as the latite flows reached the climax of their development. Ross and Smith[1]

[1] Ross, C. S., and Smith, R. L., Informal communication.

have noted that the Puye and flows of the Tschicoma group interfinger to the north of the Los Alamos area and that the materials of the fanglomerate were derived largely from brecciated portions of the flows. Pyroxene andesites of the Tschicoma group were erupted somewhat later.

While the coarsely porphyritic latites were being erupted from near the west margin of the Rio Grande depression, and were pouring eastward into it, basaltic rocks were being erupted in the interior of the depression at the site of Chino Mesa. Units 4 and 5 of these basaltic rocks were erupted contemporaneously with the deposition of the Puye conglomerate. (See p. 65.) The eruptions followed and probably were in part contemporaneous with a period of faulting in the interior of the depression. At the head of a small canyon that breaches the east wall of White Rock Canyon the lowest flow of Unit 5 rests unconformably on sediments of the undifferentiated unit of the Santa Fe group, and beneath the surface of the unconformity a truncated fault is visible. Farther southward in the canyon older and older flows of Unit 5 appear, and it is probable that the Santa Fe was being tilted southward during the initial stages of the basaltic eruptions.

There was a short period of erosion following the eruption of the flows of Unit 4 and the end of deposition of the Puye conglomerate. An easterly sloping pediment that stands approximately 400 feet above the present drainage of Guaje Canyon was cut on the Puye. This pediment, now capped by Bandelier tuff, is well developed adjacent to Guaje Canyon in the vicinity of wells G1 to G5. Later, possibly toward the end of this cycle of erosion, the pediment was partially dissected, and a lower surface was cut on the Puye near Totavi. The relation between the two surfaces is a curious one, but it appears that the lower was developed as the result of the Rio Grande making a local westward shift and that it is essentially correlative with the higher surface. Both probably are a part of Bryan's main Ortiz surface.

Following this cycle of erosion a deep canyon was cut in Units 4 and 5 of the basalts of Chino Mesa. This canyon, now filled by Bandelier tuff, lies only a short distance west of White Rock Canyon. As the basalts of Unit 3 welled up and formed steep-sided masses they blocked the flow of the Rio Grande and the old alluvium present near Totavi and elsewhere was deposited behind the steep masses as the Rio was blocked. Slightly later, two basalt flows came into the area from the southeast. These flows represented by Unit 2 of the Chino Mesa eruptions. Then, following an indefinite period of erosion, the last basaltic activity of the area occurred. The eruptions were very local and are represented by Unit 1.

The last igneous activity is represented by the rocks of the Tewa group. The eruptions commenced when a rhyolitic magma worked upward beneath the central area of Jemez volcanic series. Upward movements of the magma eventually fractured the overlying rocks and explosions threw out pumice as the upper level of magma was exposed to atmospheric pressure. This pumice dropped as ash-fall material to form the Guaje member of the Bandelier tuff. With less confinement the remaining magma surged upward, and as dissolved volatiles escaped rapidly, great volumes of pumice were expelled upward. This pumice reached the crater area in too large a volume to be thrown high in the air. Instead the material swept down the flanks of the volcanic pile as a granular-type pumice or ash flow. The debris was very mobile and rushed across the Pajarito Plateau on a gradient of something like 100 to 150 feet per mile. This ash flow and a few very thin beds of ash-fall pumice that were the product of minor explosions which nearly completed the evacuation of the magma chamber are represented by the Otowi member of the Bandelier. Some collapse of the crater area into the nearly empty magma chamber followed[1], then the last portion of

[1] Ross, C. S., and Smith, R. L., Informal communication.

volatile-poor magma was erupted to form the domes of Cerro Toledo rhyolite.

Somewhat later, during a relatively short period of erosion on the Pajarito Plateau, the Cerro Rubio quartz latite domes were intruded in the central part of the volcanic pile. By this time final activity was developing. Additional rhyolitic magma worked upward beneath the present site of the

Valles caldera and under circumstances similar to previous eruptions the culminating cycle began. A small amount of ash-fall pumice first was thrown out. This was followed immediately by large quantities of pumiceous ash and pumice that swept across the gently sloping Pajarito Plateau as ash flows. Though it is difficult to be certain, there appears to have been either two or three flows in rapid succession. Unlike the Otowi eruption this material carried with it sufficient heat to lead to a fairly complete recrystallization of the pumiceous matter. As a result of this recrystallization, the dominant portion of the Tshirege member of the Bandelier was consolidated. A little ash-fall pumice at the top of the member represents final explosion of minor magnitude.

The collapse of the Valles caldera followed. Within the caldera the domes of Valles rhyolite were extruded, possibly over a rather extended period, and the eruptions of the Tewa group came to an end.

The last geologic activity of the area consisted of faulting, the filling and draining of the lake in the Valles caldera, and the erosion that cut the canyons of the area.

Some late faulting occurred along a north-south axis near the west edge of the Pajarito Plateau as recurrent movement on pre-existing planes. The Pajarito fault zone is one of the most noticeable of these faults. At the south edge of the map this fault zone shows approximately 300 feet of throw on the top of the Bandelier tuff. Going northward the zone splits into two branches and the post-Bandelier movement dies out. Farther north are two other faults in an en-echelon position to the Pajarito zone. Unlike the latter zone, both dip to the west. The westerly of the two overlaps the northward extension of the Pajarito fault and in the area of overlap, just west of hole T4, there is a shallow syncline that developed as a result of faulting. This syncline dies out to the south. The most easterly of the two faults enters the area from the north and dies out near the head of Bayo Canyon. Both faults show only a small amount of throw on the Bandelier. One has a maximum throw of about 50 feet on this unit. The most easterly of the two, however, may have a throw as great as 500 feet on the Tschicoma group.

There are also a few northerly-trending faults near the east edge of the area, about 1 mile east of Totavi. These faults have only a few feet of throw at their exposures, but it seems possible that they may be associated with earlier faulting that may be important in the subsurface.

The previously discussed lake occupied the Valles caldera in the latter part of Pleistocene time, but it was eventually drained by the headward extension of Jemez River which has two forks that now extend to the eastern side of the caldera. The deep canyons of the Pajarito Plateau were cut mainly during the latter part of the Pleistocene.

WATER RESOURCES

GENERAL CONDITIONS AND HISTORICAL SKETCH

Los Alamos with a population of about 14,000 in 1953 is poorly located with respect to a source of water supply. An adequate source of supply for a population of more than about 3,000 cannot be obtained in the immediate vicinity of the town. The condition arose through a lack of knowledge of the water resources of the area and a number of changes in plans as to the population of the town. When the location was selected hurriedly in late 1942 as one of the project sites for the development of the atomic bomb, it was believed that the project would never require a large force of personnel and that the site would be abandoned at the end of the war. Hence, the small amount of surface water readily available on the mountain slope just west of the site appeared more than adequate for the project's needs. In the beginning it was believed that the flow of Los Alamos Canyon alone would be adequate. However, the expectations that the project would remain small and that it would be abandoned did not materialize. The town grew rapidly from its inception and in the early part of 1943 exceeded the population anticipated in original plans. As it continued to grow during the war years, the water of all the nearby streams and springs on the east slope of the Sierre de los Valles were developed. This entire flow was sufficient for a population of about 3,000. The population is reported to have reached 7,000 in 1945.

After the war, it was decided to establish the town as a permanent center for nuclear research without knowledge of the occurrence and availability of additional water. However, the crucial need for this information was realized, and the firm of Black and Veatch, Consulting Engineers, was engaged almost immediately as water-supply consultant. An examination by this firm showed that surface waters present in streams in the Valles caldera, 10 miles west of the townsite, and in the Rio Grande, 10 miles to the east, could not be claimed for use (Lawrence, 1946). The waters of these streams are considered fully appropriated, and it would have been necessary to purchase water rights for the town. Therefore, ground-water exploration was begun by the firm in the early part of 1946. The first exploration was in the vicinity of the Rio Grande, and this phase of exploration ended with the completion of wells L1 to L6 in the Los Alamos Canyon well field. These wells, ranging from 870 to 1,965 feet deep, obtained water from the undifferentiated unit of the Santa Fe and were completed near the end of 1948.

Long before wells L1 to L6 were completed, plans were laid for additional expansion of Los Alamos, and doubt arose as to the adequacy of the ground-water reservoirs in which these wells were being completed. As the wells were brought into production it was found that their water levels declined fairly rapidly. The possibility that the rapid decline would continue led Black and Veatch to the decision to attempt to locate ground water in the eastern part of the Valles caldera. A few shallow test holes were drilled in the caldera by this firm in the summer of 1948 - before wells L1 to L6 were completed in Los Alamos Canyon.

These shallow test holes, drilled under the immediate supervision of H. T. Stearns, indicated that an aquifer was present in the caldera and that additional study was advisable. This additional study was made by the Geological Survey during the summer of 1949. Water in sufficient quantities for a supply was found, but pumping tests indicated that the withdrawal of water from the small basin would affect the flow of streams that drain the caldera.

Therefore the attempt to develop this ground water was abandoned in the fall of 1949, and exploration by the Geological Survey shifted back to the Rio Grande area. Five additional wells were developed in this area between the summer of 1950 and the fall of 1951. These wells, G1 to G5 in Guaje Canyon, are all about 2,000 feet deep, and like the six wells (L1 to L6) completed between 1946 and 1948, obtain water from the undifferentiated unit of the Santa Fe group. The two groups of wells now supply nearly one billion gallons of water annually (nearly 3 mgd) and furnish nearly all of the water used by Los Alamos. However, the small surface-water sources developed during the war are still in use, yielding from one-half to one million gallons per day to the town supply.

VALLES CALDERA AREA

Surface Water

Occurrence

Water of good quality emerges at a number of places in the eastern part of the Valles caldera, the large volcanic depression west of Los Alamos. (See pl. 1.) A large number of seeps and a few small springs are present along the coalescing alluvial fans that extend inward from the steep slopes of the caldera rim and outward from the interior domes of rhyolite. A number of seeps and a spring or two are associated with the low terraces that are adjacent to the stream channels; and two small springs emerge from the edge of a rhyolite dome. The important discharge of water in the caldera, however, is at low points along the stream channels.

The springs and seeps associated with the alluvial fans are most noticeable in the late spring when lush grass around them is the first to turn green. The seeps are also most abundant at this time and countless numbers of them appear on the lower slopes of the fans, to form fairly extensive swamps in places. Some of these seeps are active until they freeze over in the fall. The few springs are all small with the individual flows ranging from about one to ten gallons per minute.

A number of seeps are present at the edges of the low terraces, and some are present at low spots on the surface of these terraces. In a few places the aggregate discharge from a number of seeps forms tiny streams, particularly in the spring of the year. At one place in the Valle Toledo (See pl. 1), north of hole H4, a small spring flowing about two gallons per minute emerges from the edge of a terrace. Below the terrace escarpments and adjacent to main drainage lines the area of channel alluvium is largely water logged. In part, at least, this water represents discharge from the terraces. This water, emerging from the terrace escarpments, has passed beneath debris on the escarpments to the area of channel alluvium.

Two small springs, each flowing less than five gallons per minute, are present near the southwest base of a large rhyolite dome (Cerro de Media). In both cases the small quantity of water soaks into the upper slopes of adjacent fan material.

The largest and the only important springs are along the drainage channels. In the Valle Toledo the dry-weather flow appears at the head of the valley. (See pl. 1.) About one mile downstream, at a point where the intermittent south branch of the drainage joins the main stem of the Rito San Antonio, the flow has increased to about 100 gallons per minute. Farther west, just above the point where the Rito enters a narrow gorge cut in Valles rhyolite, the flow is about 300 gallons per minute. About 800 gallons per minute emerges from blocky, pumiceous rhyolite in the narrow gorge at the west end of the valley. Immediately downstream from the gorge a gaging station shows the dry-weather discharge of the valley to be approximately 1,100 gallons per minute.

In the Valle Grande the dry-weather flow heads at a spring area some three-quarters of a mile northeast of hole H7. (See pl. 1.) Here, at the head of the East Fork of Jemez River, approximately 900 gallons per minute emerges from Valles rhyolite at the southeast point of a large dome (Cerro de Media). Downstream, between the gaging station below the springs and the point where Jaramillo Creek enters the main drainage, there probably is some additional gain in flow. The Jaramillo adds additional water. This creek heads to the west of the Los Alamos area. It gains some water as it flows across the Valle Grande, and at the point of entry to the East fork, it carries about 500 gallons per minute. Farther west the main creek may gain still more water toward the west end of the valley, a short distance beyond the Los Alamos area.

Availability

The surface flow of the Rito San Antonio and the East Fork of Jemez River was considered as a source of supply for Los Alamos just after the end of the war, after it had been decided to make the town a permanent center for nuclear research. The firm of Black and Veatch was retained by the

Atomic Energy Commission at this time as water supply consultants, and in their general examination of the area they considered the possibility of the utilization of the flow of both the Rito San Antonio and the East Fork of Jemez River. The possibility was abandoned as the waters were unavailable for appropriation. Indians living downstream on the main stem of Jemez River have a primordial right to this surface flow for use in irrigation. Hence, the firm of Black and Veatch turned to the Rio Grande area in the early part of 1946, and initiated the program that led to the completion near the end of 1948 of wells L1 to L6 in Los Alamos Canyon.

Ground Water

Exploration

The possibility that an exploitable body of ground water existed beneath the eastern part of the caldera seems to have been recognized first by J. F. Brown of Black and Veatch. Mr. Brown noted the surface water discussed previously (pp. 100-102) and concluded that some sort of reservoir must be present to supply the flow. As a result the firm of Black and Veatch engaged H. T. Stearns as a consultant on ground water. Mr. Stearns examined the caldera and directed the first exploratory work in the summer of 1948. Seven test holes were drilled in the caldera fill during June of that year. Most of the holes yielded some water, and one, immediately east of the site of hole H1, flowed

Plate 15.--East Fork of Jemez River in Valle Grande.

at a rate of 37 gallons per minute. In general, all of the holes indicated that the pumiceous sands and gravels of the fill were sufficiently permeable to supply water to wells. Therefore, Stearns (1948) advised that the area be considered as a source of supply and that further exploration be done.

The Atomic Energy Commission then requested the Geological Survey to make an intensive study of the area during the summer of 1949. During the summer and fall of that year 15 holes were drilled by rotary rig to test the general character and extent of the water-bearing material. Six holes (H1 to H6) were drilled in the Valle Toledo, six (H7 to H12) were drilled in the Valle Grande, and three (H13 to H16) were drilled along the eastern side of the caldera, along the divide area between the two valleys. Later, the Valle Toledo and Valle Grande holes were cased and equipped for discharge tests, to determine the hydraulic characteristics of the fill in the valleys. Holes H13 to H16 were abandoned as they appeared to have encountered material of low permeability.

Occurrence and Availability

Valle Toledo

In the Valle Toledo both water-table (nonartesian) and artesian conditions exist. Water-table conditions exist in the outlying areas immediately beneath the fans and the outer parts of the terraces. Over the greater extent of the terrace areas artesian conditions exist though the piezometric surface is below the ground surface. Below the terraces, adjacent to the stream channel, the piezometric surface is above ground level.

The six test holes, (see plate 1,) reveal an artesian reservoir which underlies most of the terrace areas. Records of these holes show that the unconsolidated material in the Caldera is as much as 500 feet thick in the valley and is underlain by domes of the Valle and Cerro Toledo rhyolites. Diagrammatic cross sections of the Valle (figures 8 and 9) show the artesian reservoir, the direction of movement of the water, recharge and discharge areas, and the piezometric surface of the artesian water (the height to which water will rise in tightly cased wells or bore holes). In areas lower than the terraces (figure 9) adjacent to the stream channel, the piezometric surface is above the ground surface and the wells drilled into the artesian reservoir yield water under sufficient artesian pressure to overflow at the land surface. The piezometric surface is more than 30 feet above the land surface in part of the area. It slopes from recharge areas toward springs (figure 8) at the west end of the valley, and to some extent towards the axial stream (figure 9), indicating the direction of movement of the water from recharge to discharge areas.

The test holes near the center of the valley showed an increase in artesian head with depth, the pressure increasing beneath successive beds of the silty to clayey material that are interbedded in the aquifer and which act as confining units. This, along with the slope of the piezometric surface and the gain in flow of the Rito San Antonio in its course through the valley, shows that in this area water is rising to some extent through the confining beds. In the outlying hole, H5, the water level in the upper part of the aquifer was higher than in the lower part, indicating that in outlying parts of the valley the water is moving downward as well as laterally.

The water available to wells exceeded expectations. The availability was most evident in the central part of the valley where the combination of permeable material and artesian head caused the loss of the first two holes drilled at the H1 site and the near loss of Hole H4. In the area of the H1 site, where the head is more than 30 feet above ground, two holes were lost when they began to flow at a rate of about 2,000 gallons per minute. Later, after a third hole was completed and developed as a well, there was a flow of about 3,000 gallons per minute for a short period with a 30-foot reduction in head. However, a discharge of this magnitude could not be maintained for a long period. Over a period of years the water available to a well or wells in the valley would be approximately equivalent to the natural discharge in the valley, approximately 1,100 gallons per minute. (See p. 102.)

Valle Grande

The test holes in the Valle Grande tapped another important artesian reservoir. Here, the unconsolidated material in the caldera is thickest and most extensive in the largest valley of the caldera. The total thickness of the saturated fill is a matter of conjecture as none of the holes encountered bedrock. It may be of the order of 2,000 feet thick over a large part of the valley, and it probably has its greatest thickness through the central, southern, and eastern parts of the valley. To the north, toward the large flat-topped dome at this side of the valley, the fill probably thins to some extent as it laps against the southward enlargement of the dome (Cerro de Medio) in the subsurface.

Hole H7, the deepest hole drilled in the valley, passed through nearly 300 feet of clay and silt that forms the confining unit in the valley and then penetrated nearly 900 feet of pumiceous sand and gravel that forms the aquifer. The more shallow outlying holes (H10 to H12) showed that the confining unit is best developed through the central part of the valley and that it interfingers with coarser clastics toward the boundaries of the valley. In these outlying areas water-table conditions exist, but over most of the valley the water is confined though the piezometric surface is a short distance below ground in the terrace areas. (See fig. 10.) Judging from holes H11 and H12 the piezometric surface may be as much as 25 or 30 feet below the land surface in the higher parts of the terrace areas. Along the lowest parts of the valley, below the terraces and adjacent to the main drainage, the piezometric surface ranges from near ground level at the main springs in the upper part of the valley to more than 25 feet above ground at hole H10 in the lower part of the valley.

The movement of water through the aquifer in the Valle Grande is less well known than in the Valle Toledo though the several holes and the discharge to the streams and springs furnish much information. The greatest movement is to the main spring area northeast of hole H7. This is indicated by the proportion of the flow of this spring to the total flow of the streams. Movement toward Jaramillo Creek appears to be relatively small in amount although this creek may gain as much as 250 gallons per minute in its course through the Valle.

The lateral movement through the central part of the valley is relatively slow as borne out by the nearly flat piezometric surface shown by the water levels of the wells. The maximum range of water levels in the widely scattered holes is only 24 feet, and the gradient from the area of hole H7 to H10 is only two feet per mile. Downward movement in places in the aquifer is indicated by the difference in head at the top and bottom of the holes. (Holes H10 and H11 showed a slightly higher water level at the top than at the bottom of the holes.) Therefore, some water is moving downward in the aquifer as far from the margins of the valley as the locations of these two holes. In the central part of the valley the water is under highest head at greatest depth. This probably indicates that some small amount of water is rising to the bed of the main creek.

The availability of water to wells is less in the Valle Grande than in the Valle Toledo. The pumiceous sands and gravels that form the aquifer are somewhat finer and apparently somewhat more silty. A discharge test run in the fall of 1949 (Theis, et al, 1950) indicated that the transmissibility of the Valle Grande aquifer is only about one-half as great as that of the Valle Toledo aquifer. The artesian head also is lower. The head was sufficiently high in only one area to cause difficulties in drilling. At the site of hole H10, where the head is about 25 feet above ground, two holes were lost before a third was completed as an observation well. However, from the standpoint of quantity of water available, there probably is about the same amount of water available in the Valle Grande as in the Valle Toledo. On an annual basis, the amount of water that could be removed from the Valle Grande is equal to the flow discharged at the main spring area, 900 gallons per minute, plus an estimated 250 discharged to the Jaramillo, or about 1,150 gallons per minute as compared with 1,100 in the Valle Toledo.

Recharge

The recharge for the ground water in the eastern part of the Valles caldera is of local origin. All of the recharge originates as precipitation which falls within the caldera. A small fraction of the precipitation escapes evaporation and transpiration and percolates downward to join the ground water body. Most of the infiltrated precipitation follows an indirect course to the caldera fill, passes through it, and emerges along the main drainage lines. Some, however, is unable to reach the fill and gives rise to the small springs and seeps along the fans and terraces. (See figs. 8, 9, and 10.)

Most of the ground-water intake occurs on the steep slopes of the area - on the interior domes, the inward facing escarpment of the caldera rim, and on the alluvial fan material adjacent to steep-sided features. Some precipitation, in part melt water from snow and in part water from direct precipitation, enters the crusts of the interior domes. The domes of Valles rhyolite, in particular, with their highly fractured, rubble covered, and commonly pumiceous crusts probably constitute the most important areas of intake. Much water is absorbed by these crusts and transmitted downward. In a few cases it reaches less permeable rhyolite in the outcrop area of the domes, as, for example, adjacent to the north boundary of the Valle Grande where two small springs emerge on the lower slopes of a dome, above the level of adjacent fan material. In general, however, the water moves farther downward before it reaches less permeable portions of the interior of the domes. This less permeable material deflects the downward percolation and the water moves laterally to the surrounding alluvial fans and caldera fill. The same sort of phenomenon also takes place on the rubble of the escarpment of the caldera rim. In this case the water moves downward only a very short distance before it reaches the impermeable rocks of the Tschicoma group or Cerro Toledo rhyolite and is deflected to the adjacent fill or fan material.

Additional recharge takes place on the upper slopes of the fans. For the most part this intake represents losses from small rivulets that pass onto the fans from the adjacent slopes of the domes and rim. Losses of this type have been noted along the north side of the Valle Grande where rivulets from the two small springs discharging on the lower slopes of a rhyolite dome reach the upper slopes of fan material and immediately soak in. Rivulets that form on the steep slopes from melting snow in the spring, and after heavy rains in the summer probably lose water as they pass across the fans. For the most part the recharge of this type probably takes place within a narrow strip on the upper parts of the fans, where the fan material is coarsest. This is indicated by seeps and small springs that emerge at lower elevations on the fans. These seeps and springs indicate that parts of the fan material are not sufficiently permeable to transmit all of the water that the fans receive downward to the unconsolidated material filling the caldera. A part of the water that enters the fans is deflected laterally and emerges on the slopes of the fans.

Disregarding the obvious discharge on the surfaces of the fan material, water moving through the fan material follows two courses. A part of the water moves downward to the caldera fill. Another part moves laterally to the alluvium that caps the low terraces. For the most part, the water that reaches this terrace material is discharged at the edges of the terraces and at low points on the surface of the terraces. (See pp. 100-102.) However, at places where the terraces extend to high elevations, far back from the main drainage, some water probably passes downward from the terrace gravel to the underlying caldera fill.

The water that reaches the unconsolidated material of the caldera by downward percolation recharges the important ground-water bodies of the Valle Toledo and Valle Grande. After reaching the fill - from the crusts of the domes, from debris on the caldera escarpment, from the fan material, and from outlying parts of terraces - the water moves slowly through the pumiceous sands and gravels to the natural outlets along the main drainage. (See pp. 100-102.) The quantity of water discharged at these natural outlets is equal in amount to the intake that reaches the fill by downward percolation in the peripheral areas of the valleys. The recharge-discharge system is in a state of approximate equilibrium.

Discharge Tests

Following the completion of the 12 exploratory holes in the two valleys, discharge tests were run in the fall of 1949 in both the Valle Toledo and Valle Grande. The tests were run to determine the production characteristics of the main wells, the hydraulic characteristics of the aquifers, and the effect of well discharge on the main springs along the stream drainage. The wells were constructed similarly, developed, and each discharge test run during a three to four day period. Data were collected during the time of the discharge and for an additional three days afterward.

Well Construction and Development

The main wells, H1 in the Valle Toledo and H7 in the Valle Grande were used to discharge water for the tests. Well H1 was constructed by first drilling 70 feet into the main confining bed of the aquifer and cementing to that depth a string of 16-inch surface casing. The hole was then drilled through the cement plug and cased to a depth of 450 feet with 12-inch pipe. In the main string of 12-inch pipe, 44 feet of wire-wrapped screen was placed between the depths of 383 and 427 feet, near the base of the caldera fill. Then, in order to draw water from all of the water-bearing units penetrated, the 12-inch pipe was perforated with a Mills knife opposite all these units, or practically throughout the interval of 80 to 340 feet. In final completion, the well was developed by pumping, by churning with a bailer, and by natural flow. The development was believed adequate when the well finally discharged approximately 3,000 gallons per minute by natural flow. Well H7 was constructed by first drilling into the confining unit to a depth of 70 feet, and cementing a string of 16-inch surface casing at a depth of 66 feet. Below this depth the 1,185-foot pilot hole was reamed to a depth of 595 feet, or through a thickness of 295 feet of water-bearing sand and gravel beneath the overlying 300 feet of clay and silt. A string of 12-inch pipe was then landed at 595 feet. This string contained five 10-foot sections of wire-wrapped screen which were spaced at intervals between the depths of 300 and 595 feet. All the intervening pipe between the screens was perforated with a torch in slots about four inches long and one-eighth inch wide. These slots were spaced four around at one-foot intervals. Hence, from 300 to 595 feet the main string was open to all adjacent material. In final completion the well was developed by churning with a bailer, by intermittent pumping, by back-flushing with a fire-engine pump, and by natural flow. At the end of the development there was a natural flow of 50 gallons per minute with a 10-foot reduction in head. It is probable that the well was not perfectly developed.

The outlying holes, H2 to H6 in the Valle Toledo and H8 to H12 in the Valle Grande, were completed for use as observation wells for the discharge tests. The construction consisted of cementing a string of 6-inch casing to depths ranging from 60 to 100 feet, generally well into the confining units of clay and silt. Inside this surface casing there was a string of two-inch tubing which had a well point 30 inches long welded on the lower end. With one exception all of the well points were landed at an altitude approximately equivalent to that of the bottom of the main wells in each of the valleys. The exception was hole H4 near the west end of the Valle Toledo. Here, the well point was landed at a depth of 240 feet, within the pumiceous crust of a dome of Valles rhyolite encountered beneath the caldera fill. Another exception in the construction of this hole was a string of 4-inch casing that extended to a depth of 219 feet. In all the wells both the 6-inch casing and the 2-inch tubing were capped and fitted with valves in order that the pressures or water levels in both the 6- and 2-inch casings could be measured. The wells were then developed by forcing water down the 2-inch casing and out the 6-inch. This development was not entirely satisfactory, and, due to caving of confining beds, the hydraulic inter-connection between the two sets of casings was somewhat variable and indefinite. In general, the head in the 6- inch casing represented the head of the upper part of the aquifer while the head in the 2-inch casing represented that of the lower part of the aquifer.

Valle Toledo test

Well H1 was shut in for three days after the development of the well had been completed. At the end of the three days the artesian pressure was near equilibrium and a three-day discharge test was run. A constant flow of 1,000 gallons per minute was maintained during the test and the decrease in head was measured with a bourdon-type pressure gage. The decrease in head at the potentially flowing observation wells - the pressures in both the 6- and 2-inch casings in holes H2, H3, and H6 and that in the 6-inch casing at H4- was measured with a mercury manometer. In the case of the 2-inch casing at holes H4 and H5, where the water levels were below ground, water-levels were measured with a steel tape or with a continuous water-level recorder. Observations could not be made in the 6-inch casing at hole H5. Following the three-day discharge period, well H1 was again shut in and recovery observations were made at all wells.

Tho three-day discharge at well H1 produced the following effects[1]:

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[1] After Theis, Chas. V., et al., Unpublished report, February 1950

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1. The head in the discharging well lowered about 20 feet from its static level of about 35 feet above ground level, indicating a specific capacity of about 50 gallons per minute per foot of drawdown.

Plate 16.--Continuous water-level recorder used to measure water level at hole H5 in the Valle Toledo. Air purge furnished by CO_2 cylinder at left.

Plate 17.--Mercury manometer used to measure artesian head at observation wells in the Valles caldera.

2. The head lowered 7.7 feet in the 2-inch and 7.3 feet in the 6-inch casing at hole H2, 302 feet west of H1.

3. The head lowered 8.2 feet in the 2-inch and 4.5 feet in the 6-inch casing at hole H3, 600 feet west of H1.

4. The head lowered 1.1 feet in the 2-inch and 1.7 feet in the 6-inch casing at hole H6, 3,600 feet east of H1.

5. The water level in the 2-inch casing at hole H5, 4,100 feet northwest of H1, rose slightly during the first hours of the test, and it lowered only 0.03 foot at the end of the first 24 hours of the test. At the end of the three-day period, when the discharge was stopped, it had lowered 0.25 foot and it continued to lower an additional 0.20 foot during the following two days. After this it began to recover.

6. There were no clearly defined effects at hole H4, 4,450 feet west of H1. There were some minor fluctuations, but they could not be related to the test. This was to be expected as the hole was cased improperly. The water in the aquifer apparently was cased off in this hole.

When viewed from a purely qualitative standpoint, the short discharge test showed that the effects of the discharging well spread rapidly through the aquifer. The continued decline of head (or water level) in most of the observation wells was clear, and showed that a longer period of discharge would have caused greater declines and more extensive effects. Therefore, a production well, discharging over a period of years, would eventually lower pressures throughout the extent of the local body of water. As the effects of discharge spread to the spring area at the west end of the valley, the flow of the springs would decrease and the flow of the Rito San Antonio would be affected correspondingly.

When viewed from a quantitative standpoint the same conclusion is reached. According to theory the discharge of a well represents a new point of discharge on a natural system that previously has been in a state of approximate equilibrium. A cone of depression spreads out from the discharging well, changing the natural gradients which previously have existed between areas of recharge and discharge, and the equilibrium is disturbed.

The formula for this cone of depression in an ideal aquifer is (Theis, 1935):

$$s = \frac{114.6F}{T} \int_{\frac{1.87r^2S}{Tt}}^{\infty} (e^{-u}/u)\, du$$

where:

s = drawdown at any point in feet.

F = rate of well discharge in gallons per minute.

T = coefficient of transmissibility

S = coefficient of storage.

t = time the well has been discharging in days.

The formula indicates indirectly that the cone will spread eventually to the area of recharge or discharge (or both), and a new equilibrium has to be established. The discharge of the well has to be balanced by an increase in recharge or by a decrease in the natural discharge - or by a combination of the two. In the case in question little if any new recharge can be drawn into the aquifer. The water table is well below ground in the areas of recharge, and hence a new equilibrium would have to be established by a decrease in the natural discharge - that is by a decrease in flow of the nearby springs. (and reduce evapotranspiration too as salvage) ?

In order to check conditions to see if the above formula was applicable, the drawdown in holes H2, H3, H5, and H6 and the recovery in holes H2, H3, and H6 were plotted against the logarithm of time since discharge began (or ended) divided by the square of the distance between the observation well and well H1. (See figs. 12a and 12b.) The points did not follow a single straight line, but they indicated that the aquifer closely approached conditions considered in the formula, and that the cone of depression would have reached the discharge area within a very short time.

The transmissibility of the aquifer has been computed by several means (Theis, et al, 1950). The drawdown and recovery of artesian head in hole H2 indicate a transmissibility of about 60,000. Using water levels at the end of the pumping period and wells H1, H2, and H3 in pairs values ranged from 40,000 to 55,000.

Valle Grande test

Well H7 was shut in for four days after being developed. It was then intended to pump the well at 500 gallons per minute for 72 hours, but the pump failed after 40 hours, and after being repaired and restarted approximately 12 hours after the time of failure, there was an additional pumping period of 48 hours. During the test and for an additional three days, water pressures were measured with a mercury manometer in both casings of holes H6, H9, and H10, and the water level measured by steel tape in the 6-inch casing of hole H11. Automatic water-stage recorders measured the water levels in the 2-inch casings of holes H11 and H12.

The 500 gallon per minute discharge at well H7 produced the following effects[1]:

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[1] After Theis, C. V., et al., Unpublished report, February, 1950.

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1. The water level of well H7 lowered approximately 50 feet, from about 10 feet above the land surface, while pumping 500 gallons per minute. This indicates a specific capacity of approximately 10 gallons a minute per foot of drawdown.

2. The head lowered 8.2 feet in the 2-inch and 8.3 feet in the 6-inch casing in hole H8, 300 feet west of H7.

3. The head lowered 4.6 feet in the 2-inch and 5.4 feet in the 6-inch casing in hole H9, 600 feet west of H7.

4. The head in the 2-inch showed erratic changes - that in 6-inch casing no perceptible changes at hole H10, 7,100 feet southwest of H7.

5. The water levels in the 2-inch casings of holes H11 and H12, and to a less extent in the 6-inch casing of H11, rose during the period of pumping and fell at its conclusions. These water-level fluctuations appeared to be correlative with barometric changes that occurred during these periods.

6. The stream gage, on the East Fork of Jemez River above the site of H7, showed the effects of the pumping. Immediately after the pump was started the gage height began to decrease, and at the time the pump failed it had declined 0.04 foot. During the 12-hour period while repairs were being made it rose 0.02 foot. It then declined 0.03 foot during the second phase of the test and began to recover immediately after the test was completed.

The effect of the well discharge on the flow of Jemez River - or actually on the flow of the springs at the head of the creek - was obvious. There was no doubt that a production well in the valley would decrease the stream flow.

The interruption of the discharge test by the pump failure made theoretical interpretation difficult. Drawdown curves were valueless, and corrected recovery curves of observation wells (fig. 12c) were imperfect, possibly because of a number of reasons. For example, the pumping period was very short, and it is believed that the development of the wells was imperfect. However, logs of the several holes in the valley demonstrate the continuity of the aquifer, and it is not unreasonable to assume that the water-bearing sands and gravels would approach the behavior of an ideal aquifer.

The corrected recovery curves of holes H8 and H9 (see appendix), the closest observation wells, though imperfect, were used to compute the transmissibility[1].

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[1] Theis, Chas. V., et al, Unpublished report, February, 1950.

It was assumed that these curves were approaching straight line plots. With this assumption, the transmissibility of the aquifer as computed from the 2-inch casing in well H8 is about 30,000; for the 6-inch casing of the same well it is a bout 27,000; for the 2-inch at well H9, about 45,000; and for the 6-inch at well H9, about 18,000. The average of the two slopes at well H9, where the greatest divergence occurs, gives a value of about 26,000.

Chemical Quality of Water

by J. D. Hem

In the course of the studies of the chemical quality of ground water and surface water in the Valles Caldera area, samples of water were obtained from the springs along the Rito San Antonio and the East Fork of Jemez River, and from the surface flow of the two streams. Samples also were obtained from the flowing test wells drilled in the Valle Toledo and Valle Grande areas. The analyses of these samples are listed in table 5 and they form the basis for the discussion of quality of water for this area in this report.

Valle Toledo

Analyses of water from five of the six test wells in the Valle Toledo are given in table 5 and one analysis is available for the 97-foot well drilled in connection with earlier studies.

In general the ground waters of this area are low in dissolved solids and soft. No sample was obtained which contained more than 143 ppm dissolved solids or 42 ppm of hardness. In most of the samples the content of silica was high (about 40 - 60 ppm), usually constituting half or more of the dissolved solids. The predominant anion in all the samples was bicarbonate, and in most instances more than half the total cations consisted of sodium. The content of dissolved matter is derived from the slow attack of the volcanic rocks by the ground water which circulates through them.

In one important respect the ground water of the Valle Toledo area differ from those of the Valle Grande area. In most water of the Valle Toledo, rather large amounts of fluoride are present. Several samples showed a concentration of 3.6 parts per million of this constituent and many of the samples contained 2.0 ppm or more.

As mentioned elsewhere in this report the observation wells were fitted with 6-inch casing to shallow depths and with 2-inch casing to lower depths. Because of the interconnection of waters between the casings this arrangement permitted imperfect sampling of water from the upper part of the aquifer through the flow from the 6-inch casing and from the lower part of the aquifer through the flow from the 2-inch casing. The perfect separation probably does not exist in most wells but some indication can be obtained from these data as to the extent of the differences which may exist between the quality of water in the upper and lower parts of the aquifer.

Samples from the observation wells show only minor differences in quality that could be attributed to the effect of depth. Water from the 97-foot well at the site of H1 contained only 0.6 ppm of fluoride. One of the holes drilled later at this site which reached a depth of 478 feet yielded water having 1.4 ppm of fluoride. The final well H1 had 2.4 ppm of fluoride except for a sample collected after a period of heavy pumping which contained 3.6 ppm.

Plate 12.--Upper part of Guaje member, (lower right) the Otowi member with conical erosional remnants, and the Tshirege (cliff) member of the Bandalier tuff. Pueblo Canyon.

These data appear to indicate that if any water of low fluoride concentration is present in this area it occurs only at shallow depths in the fill.

The iron concentration in several of the samples from the wells was high. Possibly this represents iron dissolved from the well casing.

Samples were collected from time to time during the study from the spring area at the lower end of Valle Toledo. The analyses of these samples all showed water similar in chemical character to that from the wells and all the samples contained 1.8 ppm fluoride or more. Samples of the surface flow in Rito San Antonio collected at the gaging station just below Valle Toledo show the quality is practically identical to that from the springs.

The close resemblance of the water from the wells and the springs and from the Rito San Antonio in the Valle Toledo area emphasizes the hydrologic relationship of all waters in this area. It provides further evidence that withdrawals of water from wells will reduce surface discharge from the area by an equivalent amount as the wells and springs are supplied by the same aquifer system.

Valle Grande

Chemical analyses of water from four test wells in Valle Grande are given in table 5. The water in the Valle Grande area, as indicated by these analyses and the data for springs and surface flow, are low in dissolved solids (about 100 - 150 ppm) and hardness (about 25 ppm). The silica content is high (about 60 - 75 ppm) and constitutes about half of the total mineral content. The waters closely resemble those obtained in Valle Toledo except that the water samples from Valle Grande all contained considerably less than 1.0 ppm of fluoride. There appear to be no significant differences between samples from the upper and lower part of the water-bearing zone in well H9. This is the only well for whith such a comparison can be made.

Water from the springs at the head of flow in the East Fork of Jemez River closely resembles that obtained from the wells. However, the spring water does appear to be slightly lower in dissolved solids concentration than that encountered in most of the wells.

Relation of Quality of Water to Use

The water from the Valle Toledo and Valle Grande areas is considerably below the limits where dissolved solids or hardness would be objectionable for most uses. Considering these components alone the water should be of excellent quality for domestic or industrial purposes. The large content of silica however would contribute to scale formation when the water is heated, and would be seriously objectionable in a heavy duty steam power installation. Under some conditions the water from this area may be corrosive to metal

The fluoride content of water used for domestic purposes has received considerable attention in recent years. It is generally recognized that water which contains more than about 1.5 ppm of fluoride may cause mottling of the enamel of permanent teeth of children drinking such water during the time the permanent teeth are forming. On the other hand, the presence of fluoride in a concentration of about 1.0 ppm may be helpful in strengthening the teeth of children drinking the water, and in making the teeth less susceptible to decay.

The concentration of fluoride in the Valle Toledo water is so high as to raise a serious objection to its use as the sole supply for domestic purposes. The water from Valle Grande is far superior in this respect. An equal mixture of these two waters should bring the flouride concentration near to optimum.

In general any water supply which might be developed in either Valle Grande or Valle Toledo should be expected to have a chemical quality similar to that of the present head water springs discharging from these areas into the East Fork of Jemez River and the Rito San Antonio.

EASTERN SLOPE AREA

Surface Water

Occurrence

The surface waters of the eastern slope area are represented by the flow of the few small springs and streams on the slope of the Sierra de los Valles, just west of the townsite, and that of the Rio Grande, ten miles to the east of the townsite. The Rio Grande is the master stream in the region. It has a drainage area of more than 14,600 square miles to the north, in north-central New Mexico and south-central Colorado, and the average discharge over a 48-year period at Otowi bridge at the north end of White Rock Canyon is 1,682 cubic feet per second (Paulsen, 1951, p. 296). The minimum average annual discharge of record is 128 cubic feet per second (1934) at this point. The flow of the springs and streams on the Sierra de los Valles is quite small in comparison to that of the Rio Grande. The largest stream of the Sierra, in Guaje Canyon, has a drainage area of only a few square miles and a low flow of approximately 200,000 gallons per day during dry periods. The smallest spring, Armstead No. 2 in Water Canyon, has a flow of about two gallons per minute.

Availability

The waters of the Rio Grande cannot be claimed for use by Los Alamos. According to the provisions of the Rio Grande Compact, a compact between the States of Colorado, New Mexico, and Texas and effective by the consent of Congress, the water of the Rio Grande (and its natural tributaries) were fully appropriated by downstream users long before the advent of the Los Alamos project. On the other hand, the water of the small streams and springs on the mountain slope west of the townsite apparently were not considered a part of the Rio Grande watershed, probably because the normal flows during historic times have sunk into the ground within a short distance after passing from the Sierra de los Valles to the Pajarito Plateau. Therefore, these waters were acquired and the several sources were developed one by one as the town grew during the war years. The total quantity of water available was inadequate long before the end of the war, but the conveniently located sources have furnished an economical supply and are still in use. They yield from about 100,000 to nearly 500,000 gallons per day during the dry months, usually in the fall, and from about 800,000 to 1,000,000 gallons per day in the late spring when snow is melting on the mountain slopes.

The base flow in the upper reaches of these canyons is discharged from perched water zones in the rocks of the Tschicoma group and Bandelier tuff. The water is collected by means of small intake structures and conveyed through pipe lines to the town's distribution system. As all the water emerges within or close to five main canyons, it is convenient to refer to the Guaje, Los Alamos, Pajarito, Valle, and Water Canyon sources. These designations will be used in individual descriptions that follow.

Descriptions of Surface Sources Utilized

Guaje Canyon Source

This is the best of the five surface sources and yields approximately 200,000 gallons per day during the driest months of the year. The maximum flow that has been collected during the period of snowmelt runoff in the late spring, is approximately 500,000 gallons per day. The water is collected at a small concrete dam 25 feet long and 11 feet high. This structure is at an altitude of 8,018 feet in Guaje Canyon and impounds about 250,000 gallons of water. The drainage area above the dam is about six and one-half square miles, and the perennial flow of the stream heads at two springs some two and one-half miles above the structure. Both springs issue from pumice at the base of the Tshirege member of the Bandelier tuff. One is in the main stem of the canyon, at an altitude of 8,850 feet and flows about 25 gallons per minute. The other is in a small branch canyon a short distance south, at an altitude of 8,840 feet. It flows about 40 gallons per minute. Downstream from the springs there is a gradual gain in the stream from the base of talus adjacent to the south side of the stream bed to a point about one-half mile above the intake structure.

Los Alamos Canyon Source

The flow in this canyon is impounded by a small earth-fill dam with a concrete core at an altitude of 7,657 feet in Los Alamos Canyon. The structure is about 35 feet high and impounds more than 10,000,000 gallons of water. The drainage area above the dam is approximately five and one-half square miles, almost as large as that of Guaje Canyon. The flow that is collected, however, is considerably less. The minimum flow in dry months is about 50,000 gallons per day. In the spring, when snow is melting, it has exceeded 200,000 gallons per day. The low flow represents the discharge of only two small springs. One is adjacent to the Quemazon fork of the canyon, at an altitude of 8,660 feet. The water emerges from talus, and the discharge is about 15 gallons per minute. The other spring is adjacent to the main stem of the canyon, at an altitude of 8,000 feet, where about 20 gallons per minute emerges from talus and alluvium.

Pajarito Canyon Source

The flow of this canyon is diverted by an earth and rock-fill dam at an altitude of 7,920 feet in the canyon. The structure is 6 feet high and 15 feet long. The drainage area behind this intake is one and one-half square miles, and the minimum flow appears to be about 35,000 gallons per day. The flow collected during the snow-melting period in the spring has been as high as 180,000 gallons per day. The low flow is fed by a small spring area at an altitude of 8,660 feet where the water emerges from alluvium and talus in the floor of the canyon.

Valle Canyon Source

This is the least important of the surface-water sources. The low flow is only about 10,000 gallons per day. Half of this is collected behind a low earth and rock-fill dam about 4 feet high and 15 feet long. This small structure is in Valle Canyon at an altitude of 8,240 feet, immediately below a small spring that emerges from alluvium and talus and which flows about four gallons per minute. The drainage area of the canyon above is about two square miles. The other half of the flow is collected from a small spring on the north wall of the canyon, a few hundred feet east of the small dam. This spring emerges from fractures in the Tshirege member of the Bandelier tuff. The flow of about four gallons per minute is collected behind a bulkhead. During the spring runoff, as much as 140,000 gallons of water per day have been collected at both sources.

Water Canyon Source

The water collected in this canyon is from the flow of three springs. Direct runoff from precipitation is not collected. The largest of the three springs is at an altitude of 8,000 feet in a short branch of Water Canyon. At this point a flow of about 90 gallons per minute emerges from fractures in the Tshirege member of the Bandelier tuff and is collected behind a bulkhead placed in the tuff. The other two springs are both small. One, American Spring, is a short distance south of Water Canyon, at an altitude of 8,280 feet. The water emerges at the contact between latite of the Tschicoma group and the overlying Tshirege member of the Bandelier tuff. The flow of about five gallons per minute is collected in a concrete spring box constructed around the opening. The smallest spring, Armstead No. 2, is adjacent to the floor of Water Canyon, at an altitude of 8,216 feet. The flow of about two gallons per minute emerges from fractures in latite of the Tschicoma group and is collected in a concrete spring box.

In the four canyons where intake structures are located in the stream beds, it may be noted that the water collected per unit of drainage area is not uniform. This is primarily the result of the small size of the intake structures which are not capable of storing the water of torrential flows that occur in the summer months when the precipitation is greatest. These high discharges pass over the small dams and are lost to the supply system. This bypassing has been considered in the past and thought has been given to the construction of larger impounding structures. However, as pointed out in Black and Veatch reports (1946 and 1948) the amount of additional water to be gained from the small watersheds does not justify the construction cost of additional dams. Also, as pointed out by Stearns (1948, p. 14), it would not be worthwhile to attempt to increase the spring-fed flow of the streams as the deep canyons of the Sierra de los Valles allow an outlet for most of the small perched water bodies of the area. These surface sources now yield a small but inexpensive supply of water, but attempts at major improvement would not be justified.

Ground Water

Exploration

Following the discharge tests in the Valles caldera and the confirmation that pumpage from that area would affect the flow of the associated streams, thereby interfering with the rights of downstream users, it was necessary that the exploration for ground water be shifted to the eastern slope area. Some knowledge of this area had been gained during the summer and fall of 1949, and the studies were intensified during the following winter. Development of additional wells by the summer of 1951 was necessary in order to supply the additional water needed for expansion of the town.

Some exploratory drilling had been started on the eastern slope in the summer of 1949. Hole H19 was drilled in the townsite area at that time to determine whether adequate water-bearing formations existed at economic depths, and a series of test holes in connection with the underground movement of waste products had been started during that summer. These latter holes furnished additional data on the occurrence of water. Field observations were begun in the winter of 1949. By the spring of 1950 it was decided that only the undifferentiated unit of the Santa Fe group, from which wells L1 to L6 were producing, could be expected to yield supplemental water in any important amount, but there was considerable speculation as to the satisfactory water-bearing characteristics of this unit. It had been reported that the water levels of wells L1 to L6 had declined rapidly as these wells were brought into production, and the view was prevalent that this rapid decline of levels would continue. However, field studies indicated that the undifferentiated unit of the Santa Fe group probably would support additional wells, and an exploratory hole was started at the site of well G1 in Guaje Canyon in March of 1950. While this hole was being drilled a pumping test on well L3 gave encouraging results. The test indicated that the rapid decline of water levels was incident to the first phases of pumpage and had gradully decreased. Finally, after the exploratory hole at the site of G1 was completed as a well and tested, it became evident that additional wells could be drilled in Guaje Canyon. These wells, G2 to G5, were completed in 1951.

Water of the Various Stratigraphic Units

Tschicoma Group

The rocks of the Tschicoma group are unimportant as water-bearing materials. The small quantity of ground water that emerges naturally on the slopes of the Sierra de los Valles indicates that these rocks do not contain important bodies of perched water at high elevations - at altitudes above the floors of the deep canyons cut in the Tschicoma. In spite of the deep canyons in the outcrop area, which would allow ready outlets to any contained ground water, only minor amounts are discharged to support the low flow of the small streams on the mountain slope. Two test holes failed to show important ground-water reservoirs at depth. Hole H19 in Los Alamos Canyon found the top of the main zone of saturation at a depth of about 1,200 feet. Between this depth and 2,000 feet, the bottom of the hole, the drill indicated that the rocks in which the water occurs are generally hard and massive. Therefore, it was assumed that these rocks have a low coefficient of permeability and would not yield large amounts of water to the well. Hole T4, about one mile northeast of H19, was drilled to a total depth of 1,205 feet and 21 feet into water-bearing breccia in the Tschicoma group. This hole was cased and equipped with a pump for use in waste disposal studies. Two pumping tests run on hole T4 indicated a transmissibility of approximately 1,000 for the aquifer and show that even brecciated portions of the Tschicoma group are not highly permeable. Hence, this group is unsuitable for the development of large supplies of water.

Bandelier Tuff

The Bandelier tuff lies well above the main water table. However, some perched water is present in places in this tuff, as shown by one test hole and by a few springs. Of a series of eight holes that penetrated the Bandelier, one hole (H19), yielded water. At this locality perched water was encountered between the depths of 450 and 472 feet in lump pumice of the Guaje member. Four springs emerge from perched zones in the Tshirege member, at places where this member extends to high elevations on the slopes of the Sierra de los Valles. Two of these springs, one flowing about 25, the other about 40 gallons per minute, emerge from pumice at the base of the Tshirege member near the head of Guaje Canyon. These springs form the headwaters of the stream in this canyon. (See p.131.) Another spring emerges from fractures in welded tuff of the Tshirege member in Water Canyon. This spring is at an altitude of 8,000 feet in the canyon and flows about 90 gallons per minute. A spring yielding about 4 gallons per minute is at an altitiude of 8,300 feet in Valle Canyon. This spring also emerges from fractures in welded tuff of the Tshirege member.

Puye Conglomerate

For the most part the Puye conglomerate is above the main water table, but perched water is present in places in this conglomerate, and at one locality the lower part of the conglomerate lies below the main water table.

Three test holes encountered perched water in the Totavi lentil of the Puye. Holes T1, T2, and T3 encountered water in this lentil at depths ranging from 600 to 800 feet. All of these holes were cased, equipped with small pumps, and pumping tests were run in connection with waste disposal studies. Tests at well T2, the best well of the group, showed that where the lentil is relatively free of silt the transmissibility is about 5,000. This is a fairly high value for such a thin zone of saturation. Assuming that the thickness of saturation is about 30 feet, a permeability of about 170 is indicated. Nevertheless, this water is unimportant. Large quantities of water could not be pumped from the lentil because the zone of saturation is thin.

Two test holes encountered perched water in the fanglomerate member of the Puye. Hole T1A encountered water between 212 and 215 feet, in an interflow zone between two basalt flows in the fanglomerate. Pumping tests indicate that the permeability of the interflow zone is low and that the water is present as a lens. When the lens of water is relatively large and is receiving recharge from summer rains, the well will yield three to four gallons per minute for a month or two. In the winter and spring when the lens of water is small, the well pumps dry after a pumping period of about one hour. Hole T2A encountered perched water at a depth of 110 feet in conglomerate in the fanglomerate member. This local body of water yields about five gallons per minute for a period of 10 minutes before being pumped dry.

One spring emerges from the Puye. This spring is in Ancha Canyon, about three-quarters of a mile west of the Rio Grande. The water emerges from a perched zone in the Totavi lentil, and the discharge is about 50 gallons per minute.

The lower part of the Puye is below the main water table at the site of Hole H19 in Los Alamos Canyon. Here the main water table was encountered at a depth of 1200 feet, 10 feet above the base of the fanglomerate member. Farther down the hole, below a quartz latite flow which takes the place of the lowest part of the fanglomerate member in this locality, the Totavi lentil was encountered between the depths of 1480 and 1490 feet, nearly 300 feet below the main water table. The hole was not tested for water production, but it is improbable that the 20 feet of saturation would yield important quantities of water to a well.

Basaltic Rocks of Chino Mesa

The basaltic rocks of Chino Mesa are above the main water table, and they discharge no important quantities of perched water, even where they are breached by White Rock Canyon. Therefore, it can be assumed that these rocks contain no important quantities of available water. One small spring is present about 300 yards above well L4 in Los Alamos Canyon. This spring, though emerging from alluvium, must be fed largely from the basalt that crops out immediately west. Along White Rock Canyon some water that appears as seeps and small springs adjacent to the Rio Grande probably discharges from interflow zones between the basalt flows exposed in the walls of the canyon. The water passes downward beneath talus to emerge adjacent to the stream course. The total flow of all the small springs and seeps in this canyon is not large. It is of no importance to the Los Alamos supply.

Undifferentiated Unit of the Santa Fe Group

Occurrence of Water. -- At the foot of the eastern slope, adjacent to the Rio Grande, there are exposures of the undifferentiated unit of the Santa Fe group. This unit composes the bulk of the fill of the Rio Grande depression in the area and is of great though unknown thickness. The base has not been reached in any of the supply wells which were drilled to 2,000 feet. The lateral boundaries of the unit are, on the west, faults underlying the central part of the volcanic rocks of the Jemez Mountains, and, on the east, the fault zone at the western foot of the Sangre de Cristo Mountains.

The undifferentiated unit is composed of poorly consolidated silty sandstone and sandy siltstone with some interbedded basalt. There is also some conglomerate that is important in the subsurface in Guaje Canyon, and thin beds of clay are not uncommon. These rocks compose the aquifer that yields water to the wells in Los Alamos and Guaje Canyons, the two groups of wells that supply Los Alamos.

The study of the area has shown that the undifferentiated unit is almost completely saturated. The thickness of unsaturated material at the top of the unit represents only a small fraction of the thickness of the entire fill. This unsaturated portion is thickest along the east and west margins of the Rio Grande depression. Along the margins of the depression the unsaturated upper part of the unit is as much as 500 feet thick in places. However, as the water moves from these outlying areas to the Rio Grande, the top of the zone of saturation slopes to the river, at a lesser rate than that of the general land surface. At the river all beds below stream level are saturated and the stream gains water from the ground-water body.

Water-table conditions exist near the margins of the depression, but over most of the valley the water is confined. The piezometric surface, like the water table, slopes to the river. Along the axis of Guaje Canyon this surface slopes eastward at a rate of about 70 feet per mile. East of the Los Alamos area, on the east side of the depression, its slope is westward at a rate of about 65 feet per mile. (See fig. 13.) These are general figures, and on both sides of the river there are local irregularities in the slope. In places, as between wells G4 and G5 in Guaje Canyon, the gradient of the piezometric surface is only 50 feet per mile, but between wells G2 and G3 it steepens to more than 100 feet per mile, apparently because of a buried fault between the latter two wells. Several poorly exposed faults have been noted on the surface to the west of Otowi bridge. (See pl. 1.) The faults probably are the surface expression of a fault zone which is more prominent in the subsurface.

Although it is convenient to refer to the piezometric surface as if it were a plane, such a simple condition does not exist. Because of the interlayering of beds of varying permeability in the complex aquifer, each water-bearing bed has a piezometric surface of its own, sloping to the river. The vertical spread of these numerous surfaces for various zones or beds at a given locality probably is not great, but in outlying parts of the valley, as at well G5 in Guaje Canyon, the piezometric surfaces representative of shallow water-bearing beds are several feet higher than those encountered at great depth. Water is moving downward as well as laterally in this locality. The reverse condition exists near the river. Here, the piezometric surface increases with depth. Water is rising to the river, and the piezometric surface representative of deep beds is above the land surface in areas of low topography. Hence, flowing artesian water may be obtained from deeper wells which are located at lower altitudes near the river. As examples, wells L1, L2, and L3 all flowed when they were completed, and two wells at Buckman, drilled to unknown depths a number of years ago, still flow a few gallons per minute.

Availability of Water: — Perhaps all of the various types of rock in the complex aquifer should be considered as water bearing. In the long run, as water is withdrawn from the more permeable beds by wells and the head in these beds is lowered, significant quantities of water are obtained from even the clay beds by leakage into the adjacent more permeable beds. However, the ease with which the different types of rock transmit water—or yield it directly to wells—varies with the permeability. The most permeable beds transmit and yield water most readily. The least permeable beds tend to act mainly as confining or semi-confining beds and are of little direct importance in the construction of wells except for the placement of screens.

When a well field was first being considered in Guaje Canyon, 35 samples of the undifferentiated unit were tested to determine to some extent the variation of permeability of the various types of material that crop out on the surface. Of these 35 samples, 18 were selected from five of the most permeable type beds that were exposed in the area; seven were selected from four beds that seemed to be worthy of consideration in well construction though less permeable than the best type of sandstone; and ten samples were selected from beds of relatively low permeability.

The most permeable types are pinkish gray sandstone that is very poorly cemented and which commonly shows cross-bedding. This sandstone is composed of fine to coarse sand sizes with some silt. The coefficients of permeability[1] of the 18

[1] Meinzer units, Stearns, 1928.

samples tested ranged from about five to one hundred, with most samples falling between ten and fifty. This type of sandstone composes only a small fraction of the unit, possibly five to ten percent.

Somewhat less permeable beds consist of grayish pink sandstone that is massive to thin-bedded and moderately well cemented. The seven samples from four different beds showed a range in the coefficient of permeability from about five to fifty, and five of the seven samples ranged between five and thirteen. Such beds are estimated to compose about ten to twenty percent of the formation in the area.

Samples from the more common types of rock, siltstone, very silty sandstone, and sandy siltstone ranged in the 10 samples selected from about one-tenth to five though most fell between one-tenth and one.

Samples of the thin clay beds were not tested nor the conglomerate that occurs in the subsurface in Guaje Canyon.

Though some of the permeabilities described above can be considered moderately high (100 gpd. per foot) only a very small proportion of the rocks possesses what might be considered moderate values of permeability. Accordingly, it is impossible to develop wells of high yield in the undifferentiated Santa Fe, even when a relatively great thickness of rock is penetrated, and the formation cannot be considered a "high-yielding" aquifer though it is dependable.

Recharge, Circulation, and Discharge:-- The water that occurs in the undifferentiated unit enters the ground along the margins of the Rio Grande depression, along a longitudinal strip adjacent to the boundaries of the depression. From these areas it moves very slowly through the various types of rock to the Rio Grande.

The recharge occurs by direct infiltration of precipitation and by influent seepage from small streams. In the Los Alamos area there is some direct infiltration of precipitation, probably a very small amount, on the steep slopes of the Sierra de los Valles and on the flat-lying interstream areas of the Pajarito Plateau. More important quantities probably seep into the ground from small streams and rivulets on the lower slopes of the Sierra and on the western part of the Plateau. For example, the flood runoff of such streams and rivulets rarely reaches the Rio Grande. After the heavy thunderstorms (that occur in the summer months), a great part of the water in the small streams seeps into the ground near the foot of the Sierra and on the western part of the Pajarito Plateau. In a few places there are important losses as far east as the central part of the Plateau. In Pueblo Canyon it has been noted that there are important losses just southeast of the Otowi ruins, at a point where floodwaters reach an area underlain by the Puye conglomerate and the Guaje member of the Bandelier tuff.

A part of the water that percolates downward through the rocks of the mountain and plateau areas forms local bodies of perched water in the rocks overlying the undifferentiated Santa Fe. Some of this perched water is discharged from these overlying rocks within the mountain and plateau areas and along White Rock Canyon. (See p.140.) This water does not reach the undifferentiated Santa Fe.

A larger fraction of water percolates downward to the zone of saturation in the undifferentiated Santa Fe. Here it becomes a part of a slowly moving body of water that discharges to the Rio Grande. The circulation through the flat-lying rocks of varying permeability is complex. In general, there is a considerable downward component of movement in the strip where the greatest recharge is received, and there is considerable upward component of movement near the river, where the water is rising to the stream bed from great depth. (See p.143.) There is a further complication caused by the layering of beds of varying permeability. The more permeable beds transmit greater volumes of water; the less permeable beds transmit lesser volumes. But two beds of the same transmissibility, present at different levels in the formation, transmit different quantities because of a difference in hydraulic gradient at the two different levels. The gradient is steepest at the top of the zone of saturation where water particles are moving in essentially a direct line from the recharge area to the discharge area. On the other hand, the gradient is very low along streamlines that extend to great depth and have a pronounced curvilinear trend.

The discharge to the river from both sides of the valley contributes water to the stream. This is indicated by past records of measurements of the river flow at a gaging station at Otowi Bridge and another station (Cochiti) 21 miles south. The measurements at the two stations show that there is gain in dry weather of the order of 500 or 600 gallons per minute per mile of river between the two points. This increase in water is derived largely from discharge from the undifferentiated Santa Fe though some smaller part is derived from discharge of overlying units along White Rock Canyon. (See p.140 .)

Pumping Tests:--A number of pumping tests were run in order to determine the production characteristics of wells and the hydraulic constants of the aquifer. The first test was run in the Los Alamos Canyon well field, the field developed under the supervision of Black and Veatch between 1946 and 1948. This test was run in the spring of 1950 when information was needed to substantiate exploration at the site of well G1. Later, as each of the five Guaje Canyon wells were completed, additional tests were run at each of these wells. Finally, after the completion of all the Guaje Canyon wells, a final test was run in this field in the spring of 1952.

Figure 15 shows the plan of the six wells in the Los Alamos Canyon field where the first test was run in April and May of 1950. Three of the wells (L1, L2, and L3) are 870 feet deep and three (L4, L5, and L6) range from 1,750 to 1,965 feet deep. Conditions for the test were not ideal as it was not possible to shut down all wells, wait for a nearly complete recovery, and then pump a single well while observing the effects of its discharge, inasmuch as it was necessary to supply the town with water during the experimental pumpage. To accomplish both purposes, wells L4, L5, and L6, the best wells, were selected to supply the town, and wells L1, L2, and L3, the poorest wells, were used for testing. The latter wells first were shut off for two weeks to allow the recovery of water levels to stabilize--then well L3 was pumped for two weeks--and finally the pumping at L3 was stopped and the water level allowed to recover for an additional two weeks. Water-levels were measured periodically at wells L1, L2, and L3 and at two shallow test holes closely adjacent to L1 and L3. In addition, a short test was run at well L5, one of the deeper wells. Most water-level measurements during the testing were made with a steel tape.

The test was not entirely successful. In the first place the rate of pumping at well L3 was not constant. During the two weeks pumping period of well L3 the discharge of the pump declined from 460 gallons per minute at the beginning to 300 gallons per minute at the end of the test. Further, a wide range of values of transmissibility were obtained because of the variable permeability of the aquifer, possibly in part as a consequence of faults in the area of the wells. Because of the low permeability in the locality of wells L1 and L2 the water level of L1 and an adjacent shallow test hole showed apparently only a small effect of pumpage at L3, a slight retardation of recovery during the six weeks. Less distinct consequences of the faulting in the area may have caused in part the wide range of transmissibilities computed by Theis and Conover (Theis, Chas. V., and Conover, C. S., 1950) from drawdowns and recoveries in the wells. (See table 1.)

Table 1.— Computed Values of Coefficients of Transmissibility and Storage[1] from Test in Los Alamos Canyon Well Field

Method	Coefficient of Transmissibility	Coefficient of Storage
Drawdown in well L2 as result of pumping well L3.	4,100 g.p.d. per ft.	.0033
Recovery in well L2 after pumping well L3.	4,100 "	.0033
Recovery in well L3 after pumping well L3.	1,400 "	-
Recovery in shallow test hole adjacent to well L3 after pumping well L3.	2,900 "	-
Drawdowns in wells L2 and L3 at conclusion of pumping well L3.	2,600 "	.0033
Drawdown in well L5 as result of a brief test on well L5.	6,500 "	-

[1] After Theis, C. V. and Conover, C. S., 1950

Brief pumping tests were run at each of the Guaje Canyon wells (wells G1 to G5) immediately after each of these wells had been completed. After casing and screen had been set and a gravel pack emplaced, the wells were developed with a turbine pump. The development consisted of pumping and surging until the water was clear, generally for about 48 hours. Then, when the recovery of water level following the development was essentially complete, 48-hour pumping tests were run. Figure 16 shows the plan of the wells.

The pumping tests consisted mainly of pumping each well at a constant rate for a period of 48 hours although well G3 was pumped for eight days. The constant discharge - in some cases 500, in some cases 600 gallons per minute - was measured with a calibrated orifice. During the period of pumping the water level in the wells was measured with a continuous air-line recorder. Following the period of pumping the water levels were measured with a steel tape.

The pumping level at the end of these brief pumping tests indicated that the specific capacities of the five wells ranged from about 5 to 7 gallons per minute per foot of drawdown. Points taken from the air-line recorders and plotted on semi-logarithmic paper were erratic, and these drawdown curves were of little value. The tape measurements of the recovery, however, fell very near a straight line when plotted on semi-logarithmic paper. An example of one of the plots is shown in Figure 17. Values of the transmissibility in gallons per day per foot were computed from the straight line plots using the method of Jacob (1946). In most cases the calculation was corrected to take into account a lack of complete recovery of the well from the pumping during development. An example of this correction is given in Figure 17a.

The calculated transmissibility ranged somewhat from well to well - from a low value of 7,500 at well G3 to a high value of 16,000 at well G1. Wells G2, G4, and G5 gave values of 10,000, 12,000, and 11,000, respectively. In the case of well G3, the low value probably is due to the boundary effect of a buried fault whih apparently exists between wells 2 and 3. In the case of well G1, the high value is the result of an incomplete recovery of the well before the pumping test was started and for which a correction could not be made. The values of transmissibility that ranged from 10,000 to 12,000 are believed to represent a close approximation of the transmissibility of the main water-bearing beds, i. e. the aggregate of about 400 feet of beds that are adjacent to screen in the wells. Thus, these values of transmissibility are not believed to be representative of the transmissibility of the entire aquifer. The transmissibility of the entire aquifer probably is between 15,000 and 20,000.

A 13-day pumping test was run in the Guaje Canyon well field in March of 1950, following a 30-day shutdown of the Guaje wells. Wells G1 and G5 at either end of the field were pumped continuously during the 13-day period. The discharge at well 1 varied from 535 to 520 and averaged 523 gallons per minute. The discharge at well 5 varied from 545 to 535 and averaged 539 gallons per minute. During the period of pumping, water levels were measured by steel tape at wells G2, G3, and G4; and by airline recorder at wells G1 and G5. Following the 13-day pumping period, measurements of the recovery of water levels were made by steel tape at all five wells.

By the end of the pumping period the water level of well G1 waslowered 108 feet, indicating a specific capacity of 4.8 gallons per minute per foot and at well G5 it was lowered 99 feet, indicating a specific capacity of 5.4. The water level of well 2 declined 13.2 feet; that of well 3, 5.2 feet; and that of well 4, 11.6 feet. Plots of the drawdown and recovery of water levels are shown in Figures 17b to 17k ~~in the appendix.~~

Values of the coefficients of transmissibility and storage were computed from the straight line portions of the semi-logarithmic plots, using the method of Jacob (1946). In these computations it was assumed that the effects of well G1 did not extend to well G4 and that the effects of well G5 did not reach as far east as well G2. This is a safe assumption as there is no break in the drawdown curves of wells G2 and G4 which would indicate these effects.

Computed values of the coefficients of transmissibility and storage are shown in table 2. The values of transmissibility cover a wide range, from 7,700 for one segment of the drawdown curve of well G5 to 25,000 for the recovery curve of well G4. The low value of 7,700 is spurious. The segment of the curve that yielded this value probably is indicative of a boundary effect. The average of the other values of transmissibility given in table 2 is 16,000. The coefficient of storage can be calculated only from the drawdown curves of wells G2 and G4. Both calculations of this coefficient checked closely. One curve yielded a value of 0.0002, the other 0.0004. However, as will be pointed out below, leakage from the sediments of low permeability is an important phonomenon in the aquifer, and the true value of the storage coefficient of the aquifer probably is not realized until a long period of pumping, of maybe years, has elapsed.

Table 2.--Computed Values of Coefficients of Transmissibility and Storage from 13-day Test in Guaje Canyon Well Field

Method	Coefficient of Transmissibility		Coefficient of Storage
Drawdown in well G1 as a result of pumping well G1	11,700	g.p.d. per ft.	-
Drawdown in well G2 as a result of pumping well G1	15,000	"	0.0002
Drawdown in well G4 as a result of pumping well G5	17,500	"	0.0004
Drawdown in well G5 as a result of pumping well G5	7,700	"	-
Recovery of well G1 after pumping well G1	14,700	"	-
Recovery of well G2 after pumping well G1	16,500	"	-
Recovery of well G4 after pumping well G5	25,000	"	-
Recovery of well G5 after pumping well G5	12,000	"	-

Several drawdown and recovery curves from the 13-day test show anomalous features which indicate the importance of leakage in the aquifer. The drawdown curves of wells G1, G2, and G5 (figs. 17b, 17c, and 17f) are excellent examples. The drawdown curves of these three wells were normal only during the first 100 hours of pumping. During this period, the semi-logarithmic plots show an initial adjustment in the aquifer which is followed by a series of points that lie essentially along a straight line. This straight-line sequence should have continued, with the water levels declining at a logarithmic rate. Near the 100-hour mark, however, the slope of the line through the plotted points decreases. Between the 100-hour mark and the end of the test (312 hours), the slope of the line continued to decrease indicating that a new source of water was available. Between 100 and 312 hours after pumping began, important quantities of water were leaking into the beds from which water was being removed directly by pumpage and the coefficient of storage was increasing.

The explanation of the leakage involves the lithologic character of the aquifer and the construction of the wells. The aquifer is composed of interbedded sandstone, siltstone, and clay. All of these types of beds transect the zone of saturation. However, the most permeable sandstone beds, with an aggregate thickness of about 400 feet in the 2000-foot wells, are adjacent to screen. Less permeable sandstone, siltstone, and clay are adjacent to blank casing. When the wells are pumped, water is first removed from storage in the sandstone beds, but after a period of time these beds act in considerable part as conduits. As the head declines in these sandstone beds, water begins to move into them from adjacent less permeable beds which act as reservoirs. As this process of leakage goes on, the coefficient of storage changes. Hence, values of this coefficient are related to time. The coefficient of storage computed from the 13-day test is approximately 0.0003. The value computed from the test in the Los Alamos Canyon field is approximately 0.003. The reason for the difference in the two values is not at present apparent, but in either case it appears that they can be taken as minimum values.

Decline of Water Levels:— In many aquifers the rate of decline of water levels can be predicted sith accuracy. In homogeneous aquifers of large areal extent, or having known simple boundaries, the coefficients of transmissibility and storage can be determined from pumping tests, and the rate of decline of water levels as a result of pumpage can be predicted by the Theis equation (Theis, 1935 - see p. 118). Difficulties in the application of this equation to the decline of levels in the undifferentiated unit of the Santa Fe have been indicated by pumping tests.

All of the tests show the difficulties of determining an approximate value of the coefficient of transmissibility. In addition, the 13-day test showed that the effect of leakage in the aquifer is quite important, and consequently the aquifer does not have a constant coefficient of storage. Nevertheless, as the wells are pumped and the cones of depression expand, water will be drawn from greater and greater distances, and as a first approximation the decline of levels from year to year will follow approximately a logarithmic rate.

In the Los Alamos Canyon well field (wells L1 to L6), at the beginning of 1950, after approximately two years of pumpage at an average rate of about 500 gallons per minute, there was a non-pumping water level about 35 feet below the original piezometric surface. Between the beginning of 1950 and 1953 there was an additional decline of between 25 and 30 feet, to a level between 60 and 65 feet below the original piezometric surface. This latter decline accompanied a larger pumpage rate averaging about 1,000 gallons per minute, a rate that probably will be continued approximately in the future. If it could be assumed that all conditions would remain similar to those from 1950 to 1953, a total decline of approximately 125 feet should be expected by 1975. On the other hand, pumpage from the Guaje well field (wells G1 to G5) will eventually affect the trend, and as the pumpage from this field is about equal to that of the Los Alamos field, the levels should thereafter decline at approximately twice their previous rate. There is no means of predicting the time when the effect of the Guaje wells will reach the Los Alamos field as leakage will retard the expansion of the cones of depression from these wells. However, leakage from the aquifer and the eventual reduction of the discharge from the aquifer to the Rio Grande will moderate the projected lowering with the result that the lowering probably will be less than given by the straight logarithmic projection.

Pumpage of a magnitude worth considering began in the Guaje field at the beginning of 1952. During the first year the pumpage rate averaged 660 gallons per minute, and the nonpumping level declined between 15 and 20 feet. During 1953 and succeeding years, the pumpage probably will increase to about 1,000 gallons per minute and the drawdown curve should steepen slightly. With no effect from the Los Alamos field the levels should decline toward 50 feet by 1975. However, the effect of the pumping in the Los Alamos field will eventually reach the Guaje wells, and afterwards the levels will decline at about twice their previous rate. If it is assumed that these effects will reach the field at the beginning of 1954, the levels should be about 75 feet below the original piezometric surface by 1975. This would appear to be an outside figure as increasing leakage in the aquifer probably will retard the declining water levels.

The above estimates of lowering are given only to indicate the magnitude to be expected. Because of the many complexities involved in evaluating the long term lowering, such analysis is beyond the scope of this report. Continuing data are being gathered on the changes in water levels in the supply wells along with records of pumpage. It is expected that evaluation of this data will permit a reasonably accurate prediction of the expected decline of water levels.

Chemical Quality of Water

by J. D. Hem

Samples of water have been obtained from time to time from each of the Los Alamos city supply wells in Los Alamos and Guaje canyons. The results of these analyses ~~which are in~~ (table 5) show the quality of ground water in the undifferentiated unit of the Santa Fe group which supplies the wells. Included in the table is an analysis for an abandoned railroad well at Buckman.

Water from the Los Alamos Canyon well field is low to moderate in dissolved solids. Most of the wells consistently yield water having less than 250 ppm of dissolved solids, and all yield water having less than 50 ppm hardness. Except for well L6, those which were sampled more than once show little change in quality during the period of record. Silica generally ranges between 30 and 40 ppm and is not as high in the water from these wells as in most others in the region.

Fluoride concentration in water from well L6 is more than 2.0 ppm at times. In all other wells in this field it is below 1.5 and in most of them is below 1.0. The best water is obtained from the westernmost well in this group, well L4. The predominant mineral constituents of the water from this well field are sodium and bicarbonate. Except for the fluoride of well L6 the mineral constituents of water from this well field all are within acceptable limits for domestic and most other uses.

Quality of water from several of the wells in the Los Alamos Canyon field changes slowly with time. In order to study the nature of these changes, three of the wells have been sampled several times during the investigation. Most of the changes thus far observed are minor and no definite pattern of fluctuation is apparent.

The quality of water from the Buckman well is similar to that of the water from the Los Alamos Canyon wells.

Analyses of samples of water from the five Guaje Canyon wells are included in table 5. Water from the wells in this field has a narrower range of dissolved solids concentration than the wells in Los Alamos Canyon, but the average for both fields is nearly the same. The westernmost well yields the water with the lowest dissolved solids content in this field, but this water is of the calcium bicarbonate type and has a moderate hardness. Wells farther down Guaje Canyon yield water somewhat higher in dissolved solids but softer. The silica content of the Guaje Canyon waters is comparatively high, especially that from well G1 where one sample showed a concentration of 88 ppm of silica. The silica content of the water from this well has increased notably since it was first put in use. Except for well G1 the dissolved solids content of water from the wells in this field has shown a tendency to decrease since 1951.

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Test holes in Valles Caldera Area

[illegible]	Location	Date [illegible]	Altitude, feet above sea level, of land surface (LS) and pump base (23)	Depth (feet)	Principal water-bearing unit	Original water level, feet above (+) or below (-) land surface	Specific capacity gpm/foot of draw-down	Use of water
[illegible]	[illegible]	Oct. [illegible]	[illegible]	[illegible] 1/	Caldera fill	+2[illegible].6	50	None
[illegible]	do.	[illegible]	[illegible]	[illegible]	do.	+3[illegible].4	-	Do.
[illegible]	do.	Oct. 1949	[illegible]	[illegible]	do.	+3[illegible].5	-	Do.
[illegible]	do.	[illegible]	[illegible]	[illegible] 1/	do.	-7.5	-	Do.
[illegible]	do.	[illegible]	8,7[illegible]-LS	[illegible]	do.	-[illegible].4	-	Do.
[illegible]	do.	[illegible]	[illegible](?)-LS	[illegible]	do.	+19.5	-	Do.
[illegible]	[illegible]	Nov. 1949	[illegible]	1,1[illegible] 1/	do.	+9.6	10	Do.
[illegible]	do.	Nov. 1949	8,56[illegible]-LS	595	do.	+10.8	-	Do.
[illegible]	do.	Nov. 1949	8,50[illegible].4-LS	595	do.	+11.4	-	Do.
[illegible]	do.	Nov. 1949	8,490.[illegible]-LS	589	do.	+22.9	-	Do.
[illegible]	do.	Nov. 1949	8,555.9-LS	630	do.	-10.5	-	Do.
[illegible]	do.	Nov. 1949	8,545.4-LS	534	do.	-15.4	-	Do.
[illegible]	Valle de los Posos	Oct. 1949	8,930-LS	800 1/	do.	(?)	-	Do.
[illegible]	Divide between Valle Grande and Valle de los Posos	Oct. 1949	8,990-LS	420 1/	do.	(?)	-	Do.
[illegible]	Valle Grande	Oct. 1949	8,595-LS	600 1/	do.	(?)	-	Do.
[illegible]	East [illegible] of caldera	1949	9,505-LS	1,209 1/	Tschicoma group	(?)	-	Do.
[illegible]	Valle de los Posos	1949	9,25[illegible]-LS	493 1/	do.	(?)	-	Do.

Table [illegible] of wells and test holes - Continued

Wells and Test Holes in the Eastern Slope Area

No.	Location	Date completed	Altitude, feet above sea level, of land surface (LS) and pump base (PB)	Depth (feet)	Principal water-bearing unit	Original water level, feet above (+) or below (-) land surface	Specific capacity gpm/foot of draw-down	Use of water
[illegible]	[illegible]	Nov. 1951[2]	5,9[illegible]2.6[illegible]-LS 5,97[illegible].71-PB	2,000	Undifferentiated Santa Fe group	-192.[illegible]	4.8	Public Supply
[illegible]	[illegible]	Nov. 1951[2]	[illegible]55.55-LS [illegible].15-PB	1,9[illegible]	do.	-259.5	7	Do.
[illegible]	sec.4,[illegible]	[illegible] 1951[2]	[illegible]	[illegible]	do.	-280.4	[illegible]	Do.
[illegible]	[illegible]	Nov. 1951[2]	[illegible]	[illegible]	do.	-348.9	4	Do.
[illegible]	[illegible]	Nov. 1951[2]	[illegible]30[illegible].15-LS [illegible]310.[illegible]-PB	[illegible],380	do.	-411.2	5.4	Do.
[illegible]	sec.15,[illegible]	Nov. 19[illegible]	5,[illegible]24.0-LS 5,[illegible].2-PB	870	do.	Flowed after completion	-	Do.
[illegible]	[illegible]	Dec. 19[illegible]	5,[illegible]91.0-LS 5,[illegible].5-PB	870	do.	do.	-	Do.
[illegible]	sec.15,[illegible]	[illegible]	5,[illegible]72.0-LS 5,[illegible]81.8-PB	870	do.	do.	1.4	Do.
[illegible]	[illegible]	[illegible]	5,975.0-LS 5,973.9-PB	1,965	do.	-109	6.3	Do.
[illegible]	[illegible]	Sept. 194[illegible]	5,[illegible]46.00-LS 5,[illegible].5-PB	1,750	do.	-71	3.2	Do.
[illegible]	[illegible]	Dec. 194[illegible]	5,770.00-LS 5,782.9-PB	1,790	do.	-5+	6.9	Do.

[illegible] and test holes in the Eastern Slope Area

[illegible]	Date completed	Altitude, feet above sea level, of land surface (LS) and pump base (PB)	Depth (feet)	Principal water-bearing unit	Original water level, feet above (+) or below (-) land surface	Specific capacity, gpm/foot of draw-down	Use of water
[illegible]	[illegible]	[illegible](?)LS	[illegible],000 1/	Tachicoma group	-970±	-	None
[illegible]	[illegible] 1957	[illegible]	[illegible]	Paye conglomerate	-593.1	0.2	Waste test
[illegible]	Nov. [illegible]	[illegible]	[illegible]	do.	-760.1	1	Do.
[illegible]	[illegible]	[illegible]	[illegible]	do.	-749.9	0.5	Do.
[illegible]	[illegible]	[illegible]	[illegible]	Tachicoma group	-1,166.0	0.6	Do.
[illegible]	[illegible]	[illegible]	[illegible]	-	Dry hole	-	None
do.	[illegible]	[illegible]	300	-	do.	-	Do.
[illegible]	Apr. [illegible]	[illegible],228-LS	55	-	do.	-	Do.

1/ Depth of pilot hole.

2/ Date of acceptance by Atomic Energy Commission.

Table 5.--Logs of wells and test holes.

Hole H 1, Valle Toledo

Altitude, ground surface, 8,650
Total depth, 652 feet
Drilled by Peck Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Gravel, sandy, with some clay, light gray. The fine to coarse gravel is composed of light gray rhyolite, pumiceous glass, pumice, and obsidian. The medium to coarse sand is composed of quartz and sanidine. Black silty clay is present in the upper 3 feet	0	12
Caldera fill:		
Gravel, sandy to silty, light gray. The fine to medium gravel is composed of light colored rhyolite, pumice, and pumiceous glass. The fine to coarse sand is quartz and sanidine. The silt is glassy debris	12	[illegible]
Clay, silty to sandy, diatomaceous, gray to olive	[illegible]	[illegible]
Gravel, sandy to silty, light gray. The gravel is composed mostly of pumiceous glass. The sand is quartz and sanidine. The silt is glassy debris	[illegible]	[illegible]
Gravel, sandy, with some silt, pink to buff. The fine to medium gravel is composed mostly of pink to buff pumice. The sand is mainly quartz and sanidine. Silt, composed of glassy material, is present in small amount through much of the unit and there are three well-developed silt beds between depths 115 to 120, [illegible] to [illegible], and 135 to [illegible]. This unit is [illegible]	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Hole [illegible] 1, Valle Toledo.--Continued

	Depth (feet) From	Depth (feet) To
Gravel, sandy to silty to clayey, light gray. The fine to medium gravel is composed mainly of pumice and rhyolite but there are some pieces of latite. The sand is mainly quartz and sanidine. Some silt and clay are present through most of the unit..................................	140	175
Gravel, sandy, light gray. The fine to medium gravel is composed mainly of light gray pumice but there are some pieces of rhyolite and latite. The sand is mainly quartz and sanidine. Some clayey silt is present between 310 and 325. <u>Water-bearing</u>.....................	175	345
Gravel, sandy to silty, light gray. The fine to medium gravel is composed mainly of white to light gray pumice and pumiceous glass but there are some pieces of latite. The sand is quartz and sanidine. Clayey silt occurs throughout the unit..................................	345	370
Gravel, sandy, light gray. As from 345 to 370 but without silt. <u>Water-bearing</u>....................................	370	410
Silt, clayey and sandy, yellow to olive buff to maroon.............................	410	415
Gravel, sandy to silty to clayey, light gray to gray. The fine to medium gravel is composed mainly of rhyolite, pumice and pumiceous glass. The sand is mainly quartz and sanidine. Base of the unit probably is dirty with silt..	415	[illegible]

Table 4.--Logs of wells and test holes.

Hole E 4, Valle Toledo

Altitude, ground surface, 8,603
Total depth, 385 feet
Drilled by Peck Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Gravel, sandy, with some clay, light gray. The fine to coarse gravel is composed mainly of light gray rhyolite and pumiceous glass. The sand is quartz and sanidine. Black silty clay is present in the upper 3 feet	3	10
Caldera fill:		
Clay, silty, grayish olive, with some rhyolitic debris	10	30
Gravel, sandy to silty, light gray. The fine to medium gravel is composed mainly of light gray to pale pink pumice and pumiceous glass. The sand is mainly quartz and sanidine. Grayish clayey (?) silt is present throughout the unit	30	115
Gravel, sandy, gray. The fine to coarse gravel is composed of pumice, pumiceous glass, and rhyolite. The sand is mainly quartz and sanidine. Water-bearing	115	210
Clay, silty, light red	210	212
Welded rhyolite:		
Pumiceous glass grading downward into rhyolite, light gray	212	385 T.D.

Casing record:
[illegible]-inch surface casing cemented to [illegible] feet.
[illegible]-inch casing with a 30-inch sand point at the lower end at 240 feet.

Table 4.--Logs of wells and test holes.

Hole H 5, Valle Toledo

Altitude, ground surface, 8,763
Total depth, 530 feet
Drilled by Peck Drilling Company

	Depth (feet) From	To
Terrace material:		
Gravel, sandy to silty, light gray. The fine to coarse gravel is composed mainly of rhyolite. The sand is mainly quartz and sanidine. Some silt is present	0	32
Caldera fill:		
Gravel, sandy, light gray. The fine to coarse gravel is composed mainly of rhyolite. The sand is quartz, sanidine, and rhyolitic debris	32	100
Silt, clayey to sandy, with some rhyolitic debris	100	120
Gravel, sandy to silty, light gray. The fine to coarse gravel is composed of rhyolite and pumice. The sand is mainly quartz and sanidine. Light red to buff clayey silt is present from 120 to 125, 150 to 155, and [illegible] to 170. Some silt may be present throughout the unit	120	170
Silt, clayey to sandy, and containing some gravel composed of rhyolitic debris, light maroon	170	[illegible]
Gravel, sandy to silty, light gray. The fine to coarse gravel is composed mainly of pumice. The sand is mainly quartz and sanidine. The silt present is light maroon and appears to be present through most of the unit	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Hole H 5, Valle Toledo.--Continued

	Depth (feet) From	Depth (feet) To
[illegible] indefinite. The unit appears to be gravel composed mainly of pumice	270	320
Gravel, sandy, light gray to gray. The fine to coarse gravel is composed of pumice, pumiceous glass, and rhyolite. The sand is mainly quartz and sanidine. Some brownish buff clayey silt is present between 475 and 490. <u>Water-bearing</u>	320	530 T.D.

Casing record:
[illegible]-inch surface casing cemented to [illegible] feet.
[illegible]-inch tubing, with a [illegible]-inch sand [illegible] on the lower end to [illegible] feet.

Table 4.--Logs of wells and test holes.

Hole H 6, Valle Toledo

Altitude, ground surface, 8,684(?)
Total depth, 344 feet
Drilled by Peck Drilling Company

	Depth (feet) From	To
Quaternary alluvium:		
Gravel, fine to coarse, light gray, with the pebbles composed of rhyolite and obsidian......................	0	5
Caldera fill:		
Gravel, sandy to silty, light gray. The gravel is composed mainly of rhyolite. The sand is mainly quartz and sanidine. Grayish olive clayey silt is present from 15 to 30 and the unit is dirty with silt from 40 to 50 and from 70 to 95...........................	5	95
Clay, silty to sandy, grayish olive..	95	110
Gravel, sandy, with some silt, light gray. The fine to medium gravel is composed mainly of pumice and rhyolite but some is latite. The sand is mainly quartz and sanidine. The unit is very silty from 110 to 115 and other parts of the zone appear dirty. _Water-bearing_..	110	200
Gravel, sandy, light gray. The fine to medium gravel is composed mainly of pumice and pumiceous glass but some is rhyolite and some is latite. The sand is mainly quartz and sanidine. _Water-bearing_............................	200	344 T.D.

Casing record:
6-inch surface casing was cemented to [illegible] feet.
[illegible]-inch casing with a [illegible]-inch sand screen on the lower end to 344 feet.

Table 4.--Logs of wells and test holes.

Hole H 7, Valle Grande.--Continued

	Depth (feet) From	To
As from 565 to 660, but latitic material begins to appear both in the fine gravel and sand sizes and it increases with depth..	1062	1165 T.D.

Casing record:

16-inch surface casing cemented to 66 feet.

12-inch casing to 595 feet, with five 10-foot screen sections set in at intervals between 300 and 595 feet. 12-inch casing between the five screen sections perforated by torch.

Hole H [illegible], Valle Grande

Altitude, ground surface, 8,506
Total depth, 595 feet
Drilled by Wheeler Drilling Company

Log same as that of hole H 7, 300 feet east.

Casing record:

[illegible]-inch O.D. casing to [illegible]0 feet.
[illegible]-inch casing with a 30-inch well point at the lower end to 595 feet.

Hole H [illegible], Valle Grande

Altitude, ground surface, 8,50[illegible]
Total depth, 595 feet.
Drilled by Wheeler Drilling Company

Log same as that of hole H 7, 400 feet east.

Casing record:

[illegible]-inch O.D. casing to [illegible]7 feet.
[illegible]-inch casing with a 30-inch well point at the lower end to 595 feet.

Table 4.--Logs of wells and test holes.

Hole E 10, Valle Grande

Altitude, ground surface, 8,491
Total depth, 589 feet
Drilled by Peck Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Sand, with some gravel, silt, and clay, light buff. The fine to coarse sand is composed of pumiceous glass, quartz and sanidine. The fine gravel is spherulitic rhyolite and obsidian. Most of the unit is silty and the upper two feet has some silty clay	0	15
Caldera fill:		
Gravel, sandy to clayey, gray. The fine to medium gravel is composed of rhyolite and obsidian. The sand is quartz, sanidine, and rhyolitic debris. Olive-colored clayey silt is present throughout the unit	15	70
Clay, silty to silt, clayey, diatomaceous, olive. The unit is slightly sandy and contains a little gravel from 150 to 205	70	205
Gravel, sandy, light gray to gray. The fine to coarse gravel consists of rhyolite and pumice with the pumice increasing with depth. The sand is pumiceous glass, quartz, and sanidine. The unit is silty from 205 to 225 and there may be slightly silty beds below this. Water-bearing	205	[illegible]

Casing record:
[illegible] inch casing, cemented to [illegible] feet.
[illegible] inch tubing with a [illegible]-inch well point
[illegible] feet.

Table 4.--Logs of wells and test holes.

Hole H 11, Valle Grande

Altitude, ground surface, 8,534
Total depth, 630 feet
Drilled by Wheeler Drilling Company

	Depth (feet) From	Depth (feet) To
Terrace material:		
Sand and gravel, light gray to light buff. The fine to medium gravel and fine to coarse sand consist mainly of pumice and pumiceous glass. The unit is dirty with silt from [illegible]0 to 72	0	72
Caldera fill:		
Clay, silty to silt, clayey, sandy and with some gravel. The sand and gravel are mainly pumice and pumiceous glass	72	[illegible]
Gravel, sandy to silty, light gray to light buff. The gravel consists mainly of pumice and pumiceous glass. The sand is pumice, pumiceous glass, quartz, and sanidine. The unit is dirty with silt	[illegible]	[illegible]
Silt, clayey, diatomaceous, olive green, with some gravel	120	[illegible]
Gravel, sandy to silty, light gray. The fine to medium gravel consists of pumice, pumiceous glass, and [illegible] rhyolite. The sand is pumiceous glass, quartz, and sanidine. Clayey silt is present throughout the unit	[illegible]	[illegible]
Sand, silty, gray. The fine sand is composed mainly of [illegible] [illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Hole I 11, Valle Grande.--Continued

	Depth (feet) From	Depth (feet) To
Gravel, silty, light gray to gray. The fine to coarse gravel consists of pumiceous glass and rhyolite. Clayey silt is present throughout the unit	240	275
Gravel, sandy, light gray to gray. The gravel consists mainly of pumiceous glass. The sand is pumiceous glass, quartz, sanidine, obsidian, and rhyolite. Water-bearing	275	305
Silt, clayey, olive; with some rhyolitic gravel	305	310
Gravel, sandy, light gray to gray. The fine to medium gravel consists of pumice, pumiceous glass, obsidian, and rhyolite with pumice increasing in amount with depth. The sand is mainly pumice and pumiceous glass. Parts of the unit probably are dirty with silt. Water-bearing	310	[illegible] T.D.

[illegible]:
[illegible] casing cemented to [illegible] feet.
[illegible] with a [illegible]-inch sand point [illegible] lower end to [illegible] feet.

Table 4.--Logs of wells and test holes.

Hole H 12, Valle Grande

Altitude, ground surface, 3,545
Total depth, 634 feet
Drilled by Wheeler Drilling Company

	Depth (feet) From	Depth (feet) To
Terrace material:		
Gravel, sandy, light buff. The gravel and sand consist mainly of pumice	0	55
Caldera fill:		
Silt, clayey to clay, silty, diatomaceous, olive; with traces of fine gravel	55	212
Gravel, light gray; with some sand. The gravel consists mainly of pumice and pumiceous glass. The sand is pumiceous glass, quartz, and sanidine. There apparently is some silt composed of fine glassy debris. <u>Water-bearing</u>	212	270
Gravel, sandy to silty, light gray to gray. The gravel consists of pumice and rhyolite. The sand is pumiceous glass, sanidine, quartz, and obsidian. The unit is at least slightly silty. <u>Water-bearing</u>	270	[illegible]
Gravel, sandy, light gray. The gravel consists mainly of pumice and pumiceous glass. The sand is pumiceous glass, sanidine, quartz, and obsidian. <u>Water-bearing</u>	350	634 T.D.

[illegible]:
[illegible], casing cemented to [illegible] feet.
[illegible] with a [illegible]-inch sand point [illegible] to [illegible] feet.

Table 4.--Logs of wells and test holes.

Hole H 15, Valle de los Posos

Altitude, ground surface, 3,930
Total depth, 300 feet
Drilled by Wheeler Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary fan:		
Gravel, light gray. The individual pieces are mainly light gray pumice, but some are obsidian and some are partially glassy rhyolite	0	30
Caldera fill:		
Gravel or pyroclastic debris, white to light gray. The materials are essentially all white to light gray pumice with some sand- and silt-size debris	30	300 T.D.

[illegible] casing.

Table 4.--Logs of wells and test holes.

Hole [illegible] 14, divide between Valle Grande and Valle de los Posos

Altitude, ground surface, 8,990
Total depth, 420 feet
Drilled by Peck Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary fan:		
Gravel, light gray. The individual pieces are pumice and partially glassy rhyolite. Some sand, chiefly pumiceous glass, and some silt, composed of glassy debris, also are present....................................	0	97±
[illegible] fill:		
Gravel or pyroclastic debris, light gray. The materials are pumice, pumiceous glass, and partially glassy rhyolite. Some sand and silt-size rhyolitic debris is present....................................	97	340
Gravel or pyroclastic debris, gray. The materials are latite, pumice and pumiceous glass. There is some sand-size material consisting of pumice, pumiceous glass, sanidine, and quartz. Some silt-size debris probably is present....................................	340	[illegible]
[illegible] rhyolite:		
Hyaline dome consisting of pumiceous glass with phenocrysts of sanidine, quartz, biotite, and hornblende..........................	[illegible]	420 T.D.

[illegible].

Table 4.--Logs of wells and test holes.

Hole H 15, Valle Grande

Altitude, ground surface, 8,595
Total depth, 600 feet
Drilled by Wheeler Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary fan:		
Gravel, sandy to silty, light gray. The materials are pumiceous glass, partially glassy rhyolite, and obsidian	0	7
Caldera fill:		
Silt, clayey, diatomaceous, olive	7	15
Gravel, sandy, light gray. The fine to medium gravel is composed mainly of pumice and pumiceous glass. The sand is pumiceous glass, quartz and sanidine. <u>Water-bearing</u>	15	35
Silt, clayey, diatomaceous olive. There is some sand and fine gravel composed mainly of pumice and pumiceous glass	35	125
Gravel, sandy, white to light gray. The gravel and sand are composed mainly of pumice and pumiceous glass. <u>Water-bearing</u>	125	160
Gravel, sandy, light gray. The gravel is composed of pumice and partially glassy rhyolite. The sand is mainly pumice and pumiceous glass. <u>Water-bearing</u>	160	[illegible]
Gravel, sandy, white to light gray. The gravel is mainly pumice. The sand is mainly pumice and pumiceous glass. Some diatom remains compose a part of the silt. <u>Water-bearing</u>	[illegible]	[illegible]
Gravel or pyroclastic debris, light gray. The material consists of pumice and partially glassy rhyolite. Some sand-size material, chiefly pumice and pumiceous glass, is present	[illegible]	[illegible] T.D.

Table 4.--Logs of wells and test holes.

Hole E 18, East Rim of Caldera

Altitude, ground surface, 9,305
Total depth, 1,269 feet
Drilled by Peck Drilling Company

	Depth (feet) From	Depth (feet) To
Bandelier tuff, Tshirege member:		
Tuff, welded, lavender-gray	0	295
Bandelier tuff, undifferentiated:		
Tuff, pumiceous, light gray to buff	295	427
Tschicoma group, undifferentiated unit:		
Latite, gray to grayish red, with conspicuous phenocrysts of plagioclase as much as ½-inch long and tiny phenocrysts of pyroxene, biotite, and hornblende	427	902
Quartz latite, pale gray to pale reddish gray, with conspicuous phenocrysts of plagioclase as much as ½-inch long and small to tiny phenocrysts of quartz, biotite, hornblende, and pyroxene	902	1,269 1/

1/ [illegible] Drilling.

Table 4.--Logs of wells and test holes.

Hole H 17, Valle de los Posos

Altitude, ground surface, 9,237
Total depth, 493 feet
Drilled by Wheeler Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary fan:		
Gravel, gray, composed of pieces of welded tuff..	0	10
Bandelier tuff, Tshirege member:		
Tuff, welded, pale lavender gray..	10	65
Bandelier tuff(?):		
Tuff, pumiceous, buff..	65	127
Tuff, pumiceous, light gray to pale buff, containing traces of latitic and rhyolitic debris..	127	425
Tschicoma formation, undifferentiated unit:		
Latite, gray, with conspicuous phenocrysts of plagioclase as much as ¼-inch long and tiny phenocrysts of pyroxene, biotite, and hornblende..	425	493 T.D.

[illegible].

Table 4.--Logs of wells and test holes.

Hole H 19, Los Alamos Canyon

Altitude, ground surface, 7,178
Total depth, 2,000 feet
Drilled by Jenkins Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Gravel and sand, grey. The gravel is fine to coarse and is composed of pieces of latite porphyry and welded tuff. The sand is coarse and composed of crystals and crystal fragments of quartz and sanidine. A zone of perched water occurs between 14 and 27 feet	0	27
Bandelier tuff, Tshirege member:		
Tuff, lavender-gray, nonporous, welded	27	32
Tuff, as above, but somewhat less welded and finely porous	32	124
Tuff(?). Zone contains much reddish to orange-buff, clayey to silty debris; and abundant fragments of obsidian, glassy rhyolite, and latite	124	[illegible]
Tuff, light buff, highly pumiceous, with some fragments of latite	[illegible]	[illegible]
Bandelier tuff, Otowi member:		
Tuff, highly pumiceous, pale buff	[illegible]	[illegible]
Bandelier tuff, Guaje member:		
Pumice, white, in lumps as much as [illegible] inches in diameter. Some perched water occurs between [illegible] and [illegible] feet	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Hole H 19, Los Alamos Canyon.--Continued

	Depth (feet) From	Depth (feet) To
Tschicoma group, pyroxene andesite unit:		
Andesite, dark gray; with a few tiny phenocrysts of plagioclase, as much as 1/8-inch long, and pyroxene, as much as 1/16-inch long, in a glassy groundmass much of which is finely vesicular	472	541
Andesite, dark gray to gray; with phenocrysts as from 472 to 541, in a fine-grained groundmass of plagioclase and pyroxene	541	700
Andesite, grayish purple, otherwise identical with over- and underlying rock. Zone probably is the "tops" of the underlying flow	700	715
Andesite, gray; with a few tiny phenocrysts of plagioclase and pyroxene up to 1/16-inch long in a fine-grained groundmass of plagioclase and pyroxene	715	[illegible]
Andesite, reddish brown, finely vesicular--otherwise identical with material from 715 to [illegible] [illegible] the zone represents the basal part of the overlying zone	[illegible]	[illegible]
[illegible]:		
[illegible], gray to brown. The zone is composed of angular to subangular gravel and boulders with some sand and silt. The gravel and boulder sizes are [illegible] of porphyritic latite [illegible] latite and the sand [illegible] [illegible] latitic debris	[illegible]	[illegible]

Hole T 19, Los Alamos Canyon.--Continued

	Depth (feet) From	To
Tschicoma group, undifferentiated unit:		
Quartz latite, light gray to gray; with conspicuous phenocrysts of plagioclase, as much as ¼-inch across, and less conspicuous phenocrysts of pyroxene in a glassy groundmass that grades to pumiceous glass	1,210	1,260
Quartz latite, gray to lavender gray; with conspicuous phenocrysts of plagioclase, as much as ¼-inch across, and less conspicuous phenocrysts of pyroxene, hornblende, biotite, and quartz	1,260	1,430
Totavi lentil of Puye conglomerate:		
Conglomerate, gray, composed mainly of pebbles of quartzite	1,430	1,490
Tschicoma group, undifferentiated unit:		
Quartz latite, lavender gray to purplish gray; with conspicuous phenocrysts of plagioclase and rather inconspicuous phenocrysts of quartz, hornblende, biotite and proxene	1,490	1,530
Quartz latite, purplish gray to grayish purple to brown; with phenocrysts as from 1,490 to 1,530. Zone may be largely breccia from 1,530 to 1,790, and it is all breccia from 1,790 to 1,840	1,530	1,840
Tuff breccia, light gray to very pale lavender gray, latitic. The zone is composed of colorless to whitish pumiceous glass and angular fragments of light gray to light lavender gray, semi-glassy latite that carries conspicuous phenocrysts of plagioclase, some inconspicuous phenocrysts of quartz, and a few tiny phenocrysts of biotite and hornblende	1,840	2,000 T.D.

[illegible]

Table 4.--Logs of wells and test holes.

Hole T 1, Pueblo Canyon
NE¼ Sec. 20, T. 19 N., R. 7 E.
Altitude, ground surface, 6,371
Total depth, 642 feet
Drilled by Jenkins Drilling Company

	Depth (feet) From	Depth (feet) To
Bandelier tuff, Otowi member:		
Tuff, highly pumiceous, pale buff....................	0	20
Bandelier tuff, Guaje member:		
Pumice, white, in lumps as much as 1-inch in diameter....................	20	50
Basalt, fine- to medium-grained, dark gray, with small to large phenocrysts of olivine. The lower 50 feet is breccia. This basalt belongs to the Tb[illegible] map unit....................	50	[illegible]
[illegible] conglomerate:		
Conglomerate, silty, gray. Composed of angular to subangular fragments of latitic rocks and basalt....................	[illegible]	[illegible]
Basalt, andesitic, fine- to medium-grained, medium to dark gray. This basalt correlated with Tb[illegible] map unit....................	[illegible]	[illegible]
[illegible] zone consisting of angular fragments of basalt and some silt. [illegible] of perched water....................	[illegible]	[illegible]
Basalt, andesitic, as from [illegible] to [illegible] [illegible] correlated with Tb[illegible] map unit....................	[illegible]	[illegible]
Conglomerate, gray. The zone is composed mainly of angular to subangular gravel and boulders with minor amounts of sand and silt. [illegible], however, is present in large [illegible] at the following depths: [illegible] to [illegible], [illegible] to 407, and [illegible] to [illegible]. The coarse clasts are porphyritic [illegible] quartz latites. The silt is [illegible] latitic debris....................	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Hole T 1, Pueblo Canyon.--Continued

	Depth (feet) From	To
Basalt, andesitic, very fine-grained and partially glassy, vesicular, black. This flow, tentatively correlated with the Tb_4 map unit, contains incorporated pebbles of latite and quartz latite....................................	410	510
Conglomerate, sandy to silty, gray. The materials and latitic debris including some pumiceous glass..........................	510	605
Totavi Lentil (of Puye conglomerate):		
Conglomerate, sandy to silty, with some clay. The coarse sizes are mainly subrounded pebbles of quartzite and granitic rocks. The sand is arkosic. Some pink clay occurs through the beds. Water encountered at 2[illegible] feet...	605	642 T.D.

Casing record:

[illegible]-inch I. D. casing to [illegible] feet.

1[illegible]-inch I.D. casing to 2[illegible]1 feet.

[illegible]-inch I.D. casing to [illegible] feet.

[illegible] feet of [illegible]-inch screen with 10 feet of [illegible]-inch [illegible] casing at upper end from [illegible] to [illegible] feet.

Table 4.--Logs of wells and test holes.

Hole T 2, Pueblo Canyon
NE¼ Sec. 14, T. 19 N., R. 6 E.
Altitude, ground surface, 6,646
Total depth, 789 feet
Drilled by Layne-Western Company

	Depth (feet) From	To
Quaternary alluvium:		
Gravel, sandy to silty, gray. The gravel is fine to coarse and composed of pieces of quartz latite and rhyolite tuff. The fine to coarse sand is composed mainly of crystals and crystal fragments of quartz and sanidine. The silt is fine material derived from rhyolite tuff...........................	0	11
Bandelier tuff, Otowi member:		
Tuff, highly pumiceous, pale buff. Contains a few fragments of fine-grained light gray rhyolite..	11	21
Bandelier tuff, Guaje member:		
Pumice, white, in lumps as much as 1 inch across..	21	35
Puye conglomerate:		
Conglomerate, sandy, gray. The gravel sizes, ranging from fine to coarse, are composed mainly of coarsely porphyritic quartz latite. The sand is latitic debris. Silt is present in some thin zones........................	35	105
Conglomerate, very silty, grayish buff. Sand, gravel, and boulder sizes are composed of latitic debris. The abundant tan silt is partially glassy material and contains numerous flakes of biotite and some small pieces of altered, biotite-bearing pumice............	105	110
Conglomerate, sandy, gray. The materials are latitic debris, including some biotite-bearing pumice. Perched water present in this zone..	110	115
Conglomerate, very silty, grayish buff, as [illegible] 110..	115	[illegible]

Table [illegible].--Logs of wells and test holes.

Hole T 2, Pueblo Canyon.--Continued

	Depth (feet) From	To
Puye conglomerate--Cont'd		
Conglomerate, sandy to silty, gray. The zone is composed mainly of angular to subangular gravel and boulders with lesser amounts of sand and silt. However, some thin beds are highly silty and like that from 103 to 110. The gravel and boulder sizes are composed of latitic rocks. The sand and silt are fine latitic debris, in part partially glassy material	146	300
Pumice, white to light gray, with some gravel sizes composed of latitic porphyry. The pumice, with phenocrysts of biotite, plagioclase, and quartz is by far the main constituent of the unit and occurs in lumps as much as 1-inch across. The latitic gravel occurs in some quantity through much of the unit, and in some thin beds it is as abundant as the pumice	300	[illegible]
[illegible] (of Puye conglomerate):		
Conglomerate, sandy, with a trace of [illegible], gray. The fine to coarse gravel is composed of subrounded to rounded pieces of quartz, quartzite, granite [illegible], feldspar, and volcanic rocks foreign to the area. The sand is subangular to subrounded grains of quartz, [illegible] to pinkish feldspar, and [illegible] silica. Water encountered at [illegible] feet	[illegible]	[illegible] T.D.

[illegible] record:

[illegible]-inch [illegible] casing to 57 feet.
[illegible]-inch [illegible] casing to [illegible] feet.
[illegible]-inch [illegible] casing to [illegible] feet.
3-inch [illegible] casing to [illegible] feet.
[illegible] of [illegible]-inch screen from [illegible] to [illegible] feet.

Table 4.--Logs of wells and test holes.

Hole T 3, Los Alamos Canyon
Sec. 13, T. 19 N., R. 6 E.
Altitude, ground surface, 6,625
Total depth, [illegible]15 feet
Drilled by Layne-Western Company

	Depth (feet) From	Depth (feet) To
Bandelier tuff, Otowi member:		
Tuff, highly pumiceous, pale buff; with some small fragments of latite and rhyolite	0	140
Bandelier tuff, Guaje member:		
Pumice, white to light gray, in lumps as much as 1 inch across	140	175
Puye conglomerate:		
Conglomerate, sandy to silty, gray. The subangular gravel is composed mainly of pieces of latitic porphyry, but there are traces of latitic pumice and gray glassy latite. The sand contains the same materials as the gravel. The silt, conspicuous in a few thin beds, is partially glassy debris	175	[illegible]
Basalt, andesitic, fine-to medium-grained, medium gray. This flow correlated with the [illegible] map unit	[illegible]	[illegible]
Interflow zone. Basaltic rubble with some [illegible]	327	[illegible]
Basalt, andesitic, as from [illegible] to 327 and correlated with the Tb[illegible] map unit	352	[illegible]
[illegible], light gray, with some gravel sizes composed of latitic porphyry. The [illegible] the main constituent of [illegible] and occurs in lumps ranging to [illegible] inch across. It carries [illegible] phenocrysts of quartz, [illegible] and biotite. The latitic [illegible] small amounts through [illegible], and from [illegible] to [illegible] equal in amount to the [illegible]. [illegible] is some [illegible]	[illegible]	[illegible]

Hole T 3, Los Alamos Canyon.--Continued

	Depth (feet) From	To
Puye conglomerate--Cont'd		
Conglomerate, sandy to silty, gray. Gravel and boulder sizes are composed of latitic rocks. The sand is quartz, plagioclase, and latitic debris. The silt is partially glassy material..................................	620	755
Totavi lentil (of Puye conglomerate):		
Conglomerate, sandy to silty, with some clay, gray. The gravel sizes, as much as 3 inches in diameter, consist chiefly of subrounded to rounded pieces of quartz, quartzite, granitic rocks, and volcanic rocks foreign to the area. The sand is arkosic. Some pink clay is irregularly distributed in the beds. Water encountered at 790 feet..	755	815 T.D.

Casing record:

16-inch O.D. surface casing to 33 feet.

10-inch I.D. casing to 811 feet.

10 feet of Layne screen set between 805 and 815 feet.

Table 4.--Logs of wells and test holes.
Hole T 4, Pajarito Plateau
SE¼ Sec. 9, T. 19 N., R. 6 E.
Altitude, ground surface, 7,243
Total depth, 1,205 feet
Drilled by Layne-Western Company

	Depth (feet) From	Depth (feet) To
Bandelier tuff, Tshirege member:		
Tuff, welded, light to medium gray	0	250
Tuff, pumiceous, buff, with some fragments of latite and light gray rhyolite	250	280
Bandelier tuff, Otowi member:		
Tuff, highly pumiceous, pale buff	280	368
Bandelier tuff, Guaje member:		
Pumice, light gray, in lumps as much as 2 inches in diameter	368	395
Puye conglomerate:		
Conglomerate, gray. The unit is composed of gravel and boulders of conspicuously porphyritic quartz latite	395	[illegible]
Tschicoma flow:		
Quartz latite, conspicuously porphyritic, lavender gray. This flow carries phenocrysts of plagioclase ranging to [illegible] across and small phenocrysts of quartz, augite, and resorbed biotite and hornblende	[illegible]	[illegible]
Quartz latite, conspicuously porphyritic, reddish brown. This flow carries phenocrysts essentially as the flow above though no augite was noted and the biotite and hornblende apparently are less resorbed	[illegible]	1,134
[illegible], sandy, brown. This material is [illegible] breccia of the flow above. Water encountered at 1,134 feet	1,134	1,205 T.D.

Casing record:
[illegible]-inch O.D. surface casing to [illegible] feet.
[illegible]-inch O.D. casing to 8[illegible] feet.
[illegible]-inch O.D. casing to [illegible]2 feet.
[illegible]-inch O.D. casing to 1,1[illegible] feet.
[illegible]-inch screen from 1,1[illegible] to 1,205 feet.

Table 4.--Logs of wells and test holes.

Hole T 5, Pajarito Canyon
Altitude, ground surface, 6,592
Total depth, 263 feet
Drilled by Jenkins Drilling Company

	Depth (feet) From	To
Quaternary alluvium:		
Sand and gravel, silty, gray. The medium to coarse sand is composed of quartz and sanidine. The fine to medium gravel is composed of latitic rocks and welded tuff. The silt is fine debris derived from tuff	0	23
Bandelier tuff, Tshirege member:		
Tuff, pumiceous, orange-buff	23	40
Bandelier tuff, Otowi member:		
Tuff, highly pumiceous, pale buff	40	160
Bandelier tuff, Guaje member:		
Pumice, light gray to white, in lumps as much as 1 inch across	160	171
Basalt, andesitic, fine-to medium-grained, dark gray with tiny phenocrysts of olivine, pyroxene, and plagioclase. An interflow zone present at 220 feet. These flows belong to TQb map unit	171	263 T.D.

Casing record:
[illegible]-inch O.D. surface casing to 22 feet.

Table 4.--Logs of wells and test holes.

Hole T 6, Pajarito Canyon
Altitude, ground surface, 6,705
Total depth, 300 feet
Drilled by Jenkins Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Sand and gravel, silty, gray. The fine to coarse sand is composed of quartz and sanidine. The fine to coarse gravel is composed of latitic rocks and welded tuff. The silt is fine debris derived from welded tuff	0	25
Bandelier tuff, Tshirege member:		
Tuff, slightly porous, welded, light gray	25	50
Tuff, pumiceous, orange-buff	50	85
Bandelier tuff, Otowi member:		
Tuff, highly pumiceous, pale buff	85	265
Bandelier tuff, Guaje member:		
Pumice, white to light gray, in lumps as much as 1 inch across	265	[illegible]
Puye conglomerate:		
Conglomerate, gray. The gravel and boulders are composed of latitic rocks	[illegible]	300 T.D.

[illegible]

Table 4.--Logs of wells and test holes.

Hole T 7, Ancho Canyon
Altitude, ground surface, 6,224
Total depth, 55 feet
Drilled by Jenkins Drilling Company

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Sand and gravel, gray. The medium to coarse sand is composed of quartz and sanidine. The fine to medium gravel is composed of latitic rocks........................	0	10
Bandelier tuff, Otowi member:		
Tuff, highly pumiceous, pale buff......................	10	45
Undifferentiated clay:		
Clay, silty, buff, with some fragments of basalt..	45	51
Basalt, andesitic, fine-grained, dark gray, with a few tiny phenocrysts of olivine and plagioclase. Belongs to Tb_4 map unit..	51	55 T.D.

No casing.

Table 4.--Logs of wells and test holes.

Well G 1, Guaje Canyon
SE¼ Sec. 4, T. 19 N., R. 7 E.
Altitude, ground surface, 5,973
Total depth, 2,100 feet
Drilled by Layne-Western, Inc.

	Depth (feet) From	To
Quaternary alluvium:		
Boulders, cobbles, gravel, sand, and silt. The coarse sizes are porphyritic latite. The sand is quartz and feldspar......................	0	12
Puye conglomerate:		
Conglomerate, sandy to silty, gray. The gravel and cobbles are composed of porphyritic latite. The sand is quartz, feldspar, and latitic debris.........................	12	25
Totavi lentil:		
Conglomerate, sandy, gray. The gravel is granite, pegmatitic material, and quartzite. The sand is arkosic................................	25	75
Undifferentiated unit, Santa Fe group:		
Sandstone, fine-to coarse-grained, silty, pinkish gray; with a bed of silty clay from 115 to 117. The sand is arkosic.................	75	150
Sandstone, fine-to coarse-grained, conglomeratic, pinkish gray. The sand is arkosic. The gravel sizes are porphyritic latite, quartz, quartzite, and feldspar..	150	225
Clay, sandy to silty, grayish pink.....................	225	[illegible]
Sandstone, fine-grained, clayey ranging to sandy clay, grayish pink. The sand is arkosic...	240	310
Sandstone, fine-to medium-grained, silty, grayish pink. The sand is arkosic. *Water-bearing*...	[illegible]	[illegible]
Conglomerate, sandy and silty, pinkish gray. The fine gravel is chiefly porphyritic [illegible] latite. The sand is arkosic..................	[illegible]	[illegible]
Conglomerate, as from 311 to 370 but [illegible] [illegible] of silt...................................	[illegible]	[illegible]

Table 5.--CHEMICAL QUALITY OF WATER FROM LOS ALAMOS AREA
(analyses in parts per million except where indicated)

Well	Depth (ft)	Date of Collection	TEMP. (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (Sum)	Hardness as $CaCO_3$	Specific Conductance (Micromhos at 25°C)
VALLE TOLEDO																	
Stearns	97	July 6, 1949	50	62	0.01	5.1	1.2	11		42	2.6	1.5	0.6	0.5	105	18	77.7
H1	478	do	55	59	.01	6.0	.9	9.4	1.8	40	2.6	1.5	1.4	.5	103	18	79.6
Do	652	July 27, 1949	62	59	.09	11	2.5	19		68	13	2	2.4	.5	143	58	122
Do		Sept. 20, 1949	64	57	.07	10	.4	12		42	4.3	2	3.6	.7	111	26	91.0
H2	6" csg.	Oct. 16, 1949	--	51	1.6	8.5	.9	15		48	3.7	2	3.6	.9	111	24	86.3
Do	2" csg.	do	--	49	.03	10	.4	11		43	2.9	2	3.6	.8	111	26	87.7
H3	6" csg.	do	--	45	.08	15	1.1	16		a 77	3.3	1	2.8	.8	125	42	107
Do	2" csg.	do	--	53	.19	10	.7	11		45	2.7	1	3.6	.8	105	28	83.7
H4	6" csg.	do	--	59	2.1	10	1.6	7.6		42	3.5	3	2.0	.9	90	32	85.2
H5	6" csg.	do	--	54	.02	10	1.9	16		70	3.3	2	1.6	.2	124	33	100
Do	2" csg.	do	--	59	.02	8.5	1.4	12		51	2.5	2	2.0	.5	113	27	91.0
Spring below H4		July 6, 1949	--	55	.01	6.0	.9	11		38	2.1	2.0	2.4	.3	98	18	80.4
Do		Oct. 16, 1949	56	57	.01	8.2	1.6	9.4		b 45	2.9	2	1.8	.3	105	27	80.4
Do		Oct. 10, 1950	--	54	---	---	---	---		40	---	---	2.4	---	---	--	80.2
Do		June 11, 1952	--	--	---	---	---	---		43	---	1.5	---	---	---	--	84.1
VALLE GRANDE																	
H7		Nov. 12, 1949	63	72	.26	6.2	.9	14		55	2.0	1.5	.4	.5	115	19	89.0
Do		June 20, 1950	--	71	---	6.0	2.1	11		49	2.4	1.5	.2	2.4	121	24	93.8
H8	2" csg.	Oct. 26, 1949	--	70	.02	10	2.7	15		c 75	4.1	2	.4	.3	112	8.6	109
H9	6" csg.	Oct. 26, 1949	--	74	.53	6.0	2.2	19		73	2.5	1	.6	.3	112	24	126
Do	2" csg.	Oct. 26, 1949	--	66	.02	8.0	1.6	18		64	8.2	2	.4	.2	116	26	110
H10	6" csg.	Oct. 26, 1949	--	75	.57	13	2.4	19		87	9.3	2	.2	.3	145	42	157
Valle Grande Spring		July 21, 1949	54	58	.02	6.5	1.3	11	1.0	49	2.7	1.5	.8	.6	108	22	90.6
Do		June 20, 1950	--	60	---	6.0	2.0	11		48	2.1	1.5	.8	.5	103	23	83.7
Do		Oct. 10, 1950	--	59	---	---	---	--		47	---	---	.8	---	---	--	83.8
Do		June 11, 1952	--	--	---	---	---	--		44	---	1.2	---	---	---	--	[illegible]

Table 4.--Logs of wells and test holes.

Well G 1, Quaje Canyon.--Continued

	Depth (feet) From	Depth (feet) To
Undifferentiated unit, Santa Fe group--Cont'd.		
Conglomerate, sandy to clayey, pinkish gray. The fine gravel is composed of porphyritic quartz latite. The sand is arkosic....................	470	485
Sandstone, fine-to medium-grained, silty, grayish pink. The sand is arkosic. Traces of pumice are present. Water-bearing..................	485	538
As from 485 to 538, but clayey...........................	538	570
Sandstone, fine-to coarse-grained, conglomeratic, silty, pinkish gray. The sand is arkosic. The fine gravel is composed of volcanic debris. Water-bearing..	570	635
Sandstone, fine-grained, silty to clayey, grayish pink. The sand is arkosic.....................	635	670
Sandstone, fine-to medium-grained, silty, grayish pink. The sand is arkosic. Water-bearing..	670	695
Siltstone and clay, grayish pink.........................	695	708
Sandstone, fine-to coarse-grained, pinkish gray. The sand is arkosic. Water-bearing............	708	775
Clay, silty to sandy, grayish pink to white..............	775	795
Sandstone, fine-to coarse-grained, silty, grayish pink. The sand is arkosic. Water-bearing..	795	821
Siltstone, sandy to clayey, grayish pink..................	821	847
Clay, silty to sandy, grayish pink.......................	847	855
Sandstone, fine-to medium-grained and sandy to clayey siltstone, interbedded, grayish pink. The sand is arkosic. Parts of the unit are water-bearing, as follows: [illegible] to 910 [illegible] to 940 [illegible]..	[illegible]	[illegible]

Well G 1, Guaje Canyon.--Continued

	Depth (feet) From	Depth (feet) To
Undifferentiated unit, Santa Fe group--Cont'd.		
Siltstone, clayey to sandy, grayish pink	985	1,020
Sandstone, fine-to coarse-grained, silty, grayish pink. The sand is arkosic. Water-bearing	1,020	1,055
Sandstone, fine-to medium-grained, silty to clayey, grayish pink. The sand is arkosic	1,055	1,110
Siltstone, sandy and silty sandstone, interbedded, grayish pink; with some thin beds of pink clay. Unit is water-bearing from 1,150 to 1,163 and from 1,1[illegible] to 1,178	1,110	1,210
Sandstone, fine-to coarse-grained, grayish pink. The sand is arkosic. Water-bearing	1,210	1,231
Siltstone, sandy to clayey, grayish pink	1,231	1,250
Sandstone, fine-to medium-grained, grayish pink. The sand is arkosic. Water-bearing	1,250	1,280
Siltstone, sandy to clayey, grayish pink	1,280	1,350
Sandstone, fine-to coarse-grained, grayish pink. The sand is arkosic. Water-bearing	1,350	1,395
Siltstone, sandy to clayey, grayish pink	1,395	1,440
Sandstone, fine-to coarse-grained, grayish pink. The sand is arkosic. Water-bearing	1,440	1,520
Sandstone and siltstone, clayey, grayish pink. The sand is arkosic	1,520	1,540
Basalt, fine-grained, gray to dark gray to reddish gray	1,540	1,[illegible]10

Table 4.--Logs of wells and test holes.

Well G 1, Guaje Canyon.--Continued

	Depth (feet) From	Depth (feet) To
Undifferentiated unit, Santa Fe group--Cont'd.		
Basalt breccia, gray to purplish gray to reddish brown	1,610	1,710
Basalt, fine-grained, dark gray	1,710	1,735
Basalt breccia, dark gray	1,735	1,790
Basalt, fine-grained, dark gray	1,790	1,810
Basaltic rubble and dark greenish gray clay	1,810	1,838
Sandstone, fine-to medium-grained and sandy siltstone, interbedded, grayish pink; with a few thin beds of pink clay. The sand is arkosic. Parts of the unit are water-bearing, as follows: 1,840 to 1,850 1,855 to 1,865 1,880 to 1,920 1,[illegible] to 1,980	1,838	2,100 T.D.

Table 4.--Logs of wells and test holes.

Well G 2, Guaje Canyon
SE¼ Sec. 4, T. 19 N., R. 7 E.
Altitude, ground surface, 6,056
Total depth, 2,006 feet
Drilled by Texas Water Wells, Inc.

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Boulders, cobbles, gravel, and sand. The sand is quartz, feldspar, and latitic debris. The coarser sizes are porphyritic latite and quartz latite..............................	0	13
Puye conglomerate:		
Conglomerate, sandy to silty, gray. The gravel and cobbles are composed of porphyritic latite and quartz latite. The sand is quartz, feldspar, and latitic debris. The silt is glassy to partially glassy material..................................	13	30
Tschicoma formation [illegible]:		
Conglomerate, sandy, gray. The gravel is composed of materials derived from pre-Cambrian sources. The sand is arkosic................	30	75
Undifferentiated unit, Santa Fe group:		
Sandstone, fine-to coarse-grained, conglomeratic, silty, pinkish gray. The sand is arkosic. The gravel sizes are composed of porphyritic latite..................................	75	125
Conglomerate, sandy to silty, pinkish gray. The gravel sizes are latite, quartzite, pegmatitic material, and granite. The sand is arkosic..	125	195
Sandstone, fine-to coarse-grained, silty, grayish pink. The sand is mainly arkosic but there is some latitic debris.....................	195	240
Sandstone, fine-to coarse-grained, conglomeratic, pinkish gray. The sand is arkosic. The gravel is porphyritic quartz latite and pumice. Water-bearing................................	240	[illegible]
Conglomerate, sandy and silty, pinkish gray. The fine gravel is composed of porphyritic quartz latite and pumice. The sand is arkosic. The silt is glassy debris..................	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Well G 2, Guaje Canyon.--Continued

	Depth (feet) From	To
Undifferentiated unit, Santa Fe group--Cont'd.		
Conglomerate, sandy, pinkish gray. The fine gravel is porphyritic quartz latite and pumice. The sand is arkosic. Water-bearing	393	576
Conglomerate, sandy to slightly silty, pinkish gray. Essentially identical with unit from 333 to 393 but less silt. Water-bearing	576	680
Conglomerate, sandy, silty, and clayey, grayish pink. The fine gravel is latitic debris. The sand is arkosic	680	719
Conglomerate, sandy, pinkish gray. The fine gravel is latitic debris. The sand is arkosic. Water-bearing	719	766
Conglomerate, sandy, silty and clayey, pinkish gray. The fine gravel is composed of volcanic debris. The sand is arkosic	766	830
Sandstone, fine-to coarse-grained, slightly silty. The sand is arkosic. Water-bearing	830	950
Siltstone, clayey and silty clay, grayish pink	950	970
Sandstone, fine-to medium-grained, silty, grayish pink. The sand is arkosic. Water-bearing	970	1,000
Siltstone, clayey and clay silty, grayish pink	1,000	1,036
Sandstone, fine-to coarse-grained, silty, grayish pink. The sand is arkosic. Water-bearing	1,036	1,170
Siltstone, sandy, grayish pink	1,170	1,205
Sandstone, fine-to medium-grained, very silty, grayish pink. The sand is arkosic. Unit is in part water-bearing	1,205	1,225
Clay, grayish pink	1,225	1,295

Table 4.--Logs of wells and test holes.

Well G 2, Guaje Canyon.--Continued

	Depth (feet) From	To
Undifferentiated unit, Santa Fe group--Cont'd.		
Sandstone, fine-to medium-grained and sandy siltstones, interbedded; with some thin clay beds. The sand is arkosic. Unit is water-bearing from 1,305 to 1,315 and 1,350 to 1,360	1,295	1,475
Sandstone, fine-to medium-grained, grayish pink. The sand is arkosic. Water-bearing	1,475	1,530
Sandstone, fine-to medium-grained and sandy siltstones, interbedded, grayish pink; with some thin beds of clay. The sand is arkosic. Parts of the unit are water-bearing, as follows: 1,550 to 1,560; 1,595 to 1,605; 1,645 to 1,655; 1,680 to 1,690	1,530	1,690
Siltstone, grayish pink; with some thin beds of clay	1,690	1,740
Sandstone, fine-to medium-grained, silty, grayish pink. The sand is arkosic. Water-bearing	1,740	1,760
Clay, grayish pink	1,760	1,780
Siltstone, grayish pink	1,780	1,820
Sandstone, fine-to medium-grained, silty, grayish pink. The sand is arkosic. Water-bearing	1,820	1,830
Sandstone, fine-to medium-grained and sandy siltstones, interbedded, grayish pink; with some thin beds of clay. The sand is arkosic	1,830	2,006 T.D.

Table 4.--Logs of wells and test holes.

Well G 3, Guaje Canyon
NW¼ Sec. 4, T. 19 N., R. 7 E.
Altitude, ground surface, 6,139
Total depth, 1,996 feet
Drilled by Texas Water Wells, Inc.

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Boulders, cobbles, gravel, sand, and silt. The coarse sizes are porphyritic latite and quartz latite. The sand is quartz, feldspar, and latitic debris	0	17
Puye conglomerate:		
Conglomerate, sandy to silty, gray. The cobbles and gravel are composed of latite and quartz latite. The sand is quartz, feldspar, and glassy to partially glassy debris	17	53
Totavi Lentil:		
Conglomerate, sandy, gray. The cobbles and gravel are granite, quartzite, and foreign volcanics. The sand is arkosic	53	110
Undifferentiated unit, Santa Fe group:		
Sandstone, fine-to coarse-grained, conglomeratic, pinkish gray. The sand is arkosic. The gravel is latitic debris	110	135
Clay, silty to sandy, grayish pink	135	147
Sandstone, highly conglomeratic, pinkish gray. The sand is arkosic. The fine gravel, much of which is pumice, is latitic material	147	211
As from 147 to 211 but containing much latitic silt	211	263
Conglomerate, sandy to silty, pinkish gray. The fine to medium gravel is mainly latitic pumice with subordinate porphyritic latite. The sand is arkosic	[illegible]	410
Sandstone, fine-to coarse-grained, slightly silty, grayish pink; with a trace of basaltic gravel in lower part. The sand is arkosic. [illegible]	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Well G 3, Guaje Canyon.--Continued

	Depth (feet) From	Depth (feet) To
Undifferentiated unit, Santa Fe group--Cont'd.		
Sandstone, fine-to medium-grained, silty to clayey, grayish pink. The sand is arkosic...........	433	471
Conglomerate, sandy to silty, pinkish gray; with some pink clay................................	471	501
Sandstone, conglomeratic, pinkish gray. The fine to coarse sand is arkosic. The gravel sizes are volcanics. <u>Water-bearing</u>..	501	556
Sandstone, fine-to medium-grained, silty, grayish pink. The sand is arkosic..........................	556	566
Sandstone, fine-to coarse-grained, conglomeratic, pinkish gray. The sand is arkosic. The gravel sizes are volcanic debris. <u>Water-bearing</u>..	566	589
Siltstone, sandy to clayey, grayish pink................	589	596
Sandstone, fine-to coarse-grained, grayish pink. The sand is arkosic. <u>Water-bearing</u>...........	596	655
Sandstone, fine-to coarse-grained, pinkish gray. The sand is arkosic. <u>Water-bearing</u>...........	655	684
Sandstone, fine-to medium-grained, silty to clayey, grayish pink. The sand is arkosic..	684	719
Sandstone, fine-to coarse-grained, grayish pink. The sand is arkosic. <u>Water-bearing</u>...........	719	765
Clay, grayish pink, silty............................	765	774
Sandstone, fine-to coarse-grained, pinkish gray. The sand is arkosic. <u>Water-bearing</u>...........	774	800
Sandstone, fine-to medium-grained, somewhat silty, grayish pink. The sand is arkosic. <u>Unit is water-bearing from 821 to 849</u>................	800	849
Siltstone, sandy to clayey, grayish pink...............	849	[illegible]

Well G 3, Guaje Canyon.--Continued

	Depth (feet) From	To
Undifferentiated unit, Santa Fe group--Cont'd.		
Sandstone, fine-to medium-grained, silty to clayey, grayish pink. The sand is arkosic. Unit is water-bearing from 888 to 909	888	921
Basalt, fine-grained, dark greenish gray	921	936
Sandstone, fine-to medium-grained, slightly silty, grayish pink; with some thin beds of pink clay. The sand is arkosic. Water-bearing	936	1,000
Clay, grayish pink, silty to sandy	1,000	1,012
Basalt breccia, reddish brown to reddish gray; with some admixed sand	1,012	1,090
Clay, grayish pink, silty to sandy	1,090	1,095
Sandstone, fine-to medium-grained, somewhat silty, grayish pink. The sand is arkosic. Water-bearing from 1,109 to 1,134	1,095	1,134
Clay, silty to sandy, grayish pink	1,134	1,141
Sandstone, fine-to medium-grained, silty. grayish pink. The sand is arkosic. Water-bearing	1,141	1,176
Sandstone, fine-grained, silty, and siltstone sandy, grayish pink. The sand is arkosic. In part water-bearing	1,176	1,312
Clay, sandy, grayish pink	1,312	1,329
Sandstone, fine-to medium-grained, somewhat silty, grayish pink. The sand is arkosic. Water-bearing	1,329	1,365
Sandstone, fine-grained, and sandy siltstone, grayish pink. The sand is arkosic	1,365	1,391
Sandstone, fine-to medium-grained, somewhat silty, grayish pink. The sand is arkosic. Water-bearing	1,391	1,426

Table 4.--Logs of wells and test holes.

Well G 3, Guaje Canyon.--Continued

	Depth (feet) From	To
Undifferentiated unit, Santa Fe group--Cont'd.		
Siltstone, clayey to sandy, grayish pink...............	1,426	1,467
Sandstone, fine-grained, silty, and silty sandstone, interbedded, grayish pink; with some thin beds of pink clay. The sand is arkosic. Parts of the sequence are water-bearing, as follows: 1,467 to 1,599 1,750 to 1,770.................................	1,467	1,998 T.D.

Table 4.--Logs of wells and test holes.

Well G 4, Guaje Canyon
NE¼ Sec. 5, T. 19 N., R. 7 E.
Altitude, ground surface, 6,229
Total depth, 2,002 feet
Drilled by Texas Water Wells, Inc.

	Depth (feet) From	To
Quaternary alluvium:		
Boulders, cobbles, gravel, sand, and silt. All materials are of latitic composition................	0	15
Puye conglomerate:		
Conglomerate, sandy to silty, gray. The coarse sizes (gravel, cobbles, and few boulders) are of porphyritic latite. The sand is quartz, feldspar, and latitic debris. The silt is glassy to partially glassy material..	15	60
Totavi Lentil:		
Conglomerate, sandy, gray. The gravel sizes are mainly materials from pre-Cambrian sources. The sand is arkosic..........................	60	120
Undifferentiated unit, Santa Fe group:		
Sandstone, fine-to coarse-grained, conglomeratic, pinkish gray. The sand is arkosic. The gravel sizes are porphyritic latite...................	120	168
Siltstone, sandy to clayey, grayish pink.................	168	180
Sandstone, conglomeratic, as from 120 to 168..............	180	281
Siltstone, as from 168 to 180...........................	281	297
Conglomerate, sandy to silty, pinkish gray. The fine to medium gravel sizes are composed of porphyritic latite and pumice. The sand is arkosic. Unit is water-bearing from [illegible] to 499...	297	499
Basalt, fine-grained dark gray. The upper and lower 5 feet of the flow are highly vesicular..........	499	526
Sandstone, fine-to coarse-grained, conglomeratic, pinkish gray. The sand is arkosic. The fine gravel sizes are volcanic materials..........	526	556

Table 4.--Logs of wells and test holes.

Well G 4, Guaje Canyon.--Continued

	Depth (feet) From	Depth (feet) To
Undifferentiated unit, Santa Fe group--Cont'd.		
Siltstone, clayey to sandy, and with some gravel, grayish pink. The gravel sizes are volcanic materials	536	551
Sandstone, conglomeratic, in part silty, pinkish gray. The sand is arkosic. The gravel is composed of volcanic materials. Unit is water-bearing from 551 to 563 and from 571 to 601	551	601
Siltstone, as from 536 to 551	601	646
Sandstone, conglomeratic, with some thin beds of siltstone, pinkish gray. The fine to coarse sand is arkosic. The fine gravel is volcanic material. Water-bearing	646	681
Sandstone, fine-to coarse-grained, slightly silty, pinkish gray. There is a little gravel, composed of volcanics, included in the arkosic sand. Water-bearing	681	722
Siltstone, sandy to clayey, grayish pink	722	746
Sandstone, fine-to coarse-grained, slightly silty, grayish pink. The sand is arkosic. Water-bearing	746	772
Siltstone, sandy, grayish pink	772	800
Sandstone, fine-to coarse-grained, slightly silty, grayish pink. The sand is arkosic. Water-bearing	800	816
Siltstone, grayish pink	816	833
Sandstone, fine-to medium-grained, slightly silty, grayish pink. The sand is arkosic. Water-bearing	833	855
Basalt, fine-grained, dark reddish gray	855	891
Basalt breccia, gray to dark gray	891	[illegible]
Sandstone, fine-to medium-grained, silty to clayey. The sand is arkosic	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Well G 4, Guaje Canyon.--Continued

	Depth (feet) From	To
Undifferentiated unit, Santa Fe group--Cont'd.		
Basaltic rubble, with some admixed sand and clay..	[illegible]	975
Sandstone, fine-to medium-grained, slightly silty, grayish pink. The sand is arkosic. Water-bearing..	975	985
Clay, silty to clayey siltstone, with some sand, grayish pink..	985	1,001
Sandstone, fine-to coarse-grained, slightly silty, pinkish gray. The sand is arkosic. Water-bearing..	1,001	1,024
Siltstone and fine-grained sandstone, interbedded, with some thin clay beds, grayish pink. The unit is probably water-bearing from 1041 to 1,0[illegible]..	1,024	1,105
Basalt, fine-grained, dark gray........................	1,105	1,141
Siltstone and fine-grained sandstone, interbedded, grayish pink..	1,141	[illegible]
Sandstone, fine-to medium-grained, grayish pink. The sand is arkosic. Water-bearing...........	[illegible]	1,194
Sandstone and siltstone interbedded, grayish pink with some thin beds of clay. The sand is arkosic..	1,194	1,240
Clay, grayish pink..	1,240	1,251
Sandstone, fine-to medium-grained, somewhat silty, and with some thin clay beds, grayish pink. The sand is arkosic. Water-bearing..	[illegible]	[illegible]
Clay, [illegible] pink..	[illegible]	[illegible]
Sandstone, silty and sandy siltstone, [illegible], grayish pink. The sand is [illegible]..	[illegible]	[illegible]
Sand[illegible], fine-to coarse-grained, grayish [illegible]. The sand is arkosic. Water-bearing...........	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Well G 5, Guaje Canyon
NW¼ Sec. 5, T. 19 N., R. 7 E.
Altitude, ground surface, 6,306
Total depth, 1,997 feet
Drilled by Texas Water Wells, Inc.

	Depth (feet) From	Depth (feet) To
Quaternary alluvium:		
Boulders, cobbles, gravel, sand, and silt. All materials are of latitic composition	0	8
Puye conglomerate:		
Conglomerate, sandy to silty, gray. The coarse sizes (gravel and cobbles) are mainly conspicuously porphyritic latite and quartz latite with subordinate amounts of latitic pumice. The sand sizes are quartz, feldspar, and latitic materials. The silt is glassy debris	8	127
Undifferentiated unit, Santa Fe group:		
Siltstone, clayey, grayish pink	127	148
Sandstone, friable, fine-to coarse-grained, somewhat conglomeratic, gray. The sand grains are quartz, colorless to pink feldspar, and pink to yellow chalcedonic silica	148	210
Clay, silty to sandy, grayish pink, with some fine gravel composed of latitic materials	210	220
Conglomerate, pinkish gray. The fine to medium gravel sizes are composed of latitic pumice and subordinate porphyritic latite. A small amount of arkosic sand is present	220	[illegible]
Conglomerate, pinkish gray. The fine to medium gravel sizes are composed of porphyritic latite and subordinate latitic pumice. A small amount of arkosic sand is present	[illegible]	347
Conglomerate, as from [illegible] to 347 but containing more latitic silt	347	[illegible]
Conglomerate, sandy to silty, pinkish gray. The fine gravel sizes are composed of latitic porphyry and latitic pumice. The sand is arkosic. The beds seem free of silt from 456 to 472 and [illegible]	[illegible]	[illegible]

Table 4.--Logs of wells and test holes.

Well G 5, Guaje Canyon.--Continued

	Depth (feet) From	Depth (feet) To
Undifferentiated unit, Santa Fe group--Cont'd.		
Clay, grayish pink, containing some latitic gravel..	471	486
Conglomerate, sandy to slightly silty, pinkish gray. The fine gravel sizes are mainly latitic pumice. The sand is arkosic. Water-bearing..	486	523
Sandstone, fine-to medium-grained, silty, grayish pink; with some fine gravel sizes composed mainly of latitic pumice. The sand is arkosic..	523	586
Basalt, fine-grained, dark gray. The upper and lower 5 feet of the flow are highly vesicular..	586	615
Conglomerate, sandy, pinkish gray. The fine gravel sizes are volcanic materials, apparently derived from a nearby source. The sand is arkosic. Water-bearing............................	615	679
Conglomerate, as from 615 to 679 but very silty..	679	695
Conglomerate, as from 615 to 679. Water-bearing..	695	737
Conglomerate, sandy to silty, pinkish gray. The fine gravel sizes are composed of volcanic materials. The sand is arkosic...............	737	[illegible]
Sandstone, fine-to medium-grained, arkosic, silty, grayish pink. Water-bearing..................	[illegible]	[illegible]
Siltstone, sandy to clayey, grayish pink................	[illegible]	[illegible]
Sandstone, fine-to coarse-grained, pinkish gray. The sand is arkosic. Water-bearing...........	[illegible]	[illegible]
Basalt, fine-grained, dark gray...........................	[illegible]	[illegible]
Basalt, scoria, dark gray to reddish brown.............	[illegible]	[illegible]
Basalt, fine-grained, dark gray to reddish [illegible]..	[illegible]	1,[illegible]

Table [illegible].--Logs of wells and test holes.

Well G 5, Guaje Canyon.--Continued

	Depth (feet) From	To
Undifferentiated unit, Santa Fe group--Cont'd.		
Basalt, fine-grained, dark gray	1,009	1,071
Basalt breccia, reddish brown	1,071	1,076
Sandstone, fine-grained, silty to clayey, reddish pink. The sand is arkosic	1,076	1,093
Basalt breccia, dark gray to brown. The lower 10 feet contains much sand and clay	1,093	1,135
Clay, silty to sandy, grayish pink	1,135	1,145
Sandstone, fine-to medium-grained, slightly silty, grayish pink. The sand is arkosic. <u>Water-bearing</u>	1,145	1,171
Siltstone, sandy to clayey, grayish pink	1,171	1,211
Basalt, fine-grained, dark gray	1,211	1,258
Sandstone, fine-grained, reddish pink, arkosic	1,258	1,241
Basalt, fine-grained, dark gray	1,241	1,286
Clay, dark maroon	1,286	1,291
Basalt, fine-grained, dark gray	1,291	1,313
Siltstone, sandy to clayey, grayish pink	1,313	1,359
Sandstone, fine-to medium-grained, arkosic. <u>Water-bearing</u>	1,359	1,387
Siltstone, sandy to clayey, grayish pink	1,387	1,427
Sandstone as from 1,359 to 1,387. <u>Water-bearing</u>	1,427	1,471
Siltstone as from 1,387 to 1,427	1,471	1,491

Table 4.--Logs of wells and test holes.

Well G 5, Guaje Canyon.--Continued

	Depth (feet) From	To
Undifferentiated unit, Santa Fe group--Cont'd.		
Sandstone and siltstone, interbedded, as the five preceding units, and containing a few thin beds of pink clay. The sand is arkosic. Some beds are water-bearing, as follows: 1,491 to 1,519 1,536 to 1,546 1,551 to 1,566 1,659 to 1,695 1,706 to 1,749 1,810 to 1,831	1,491	1,997 T.D.