Geology and Ground-Water Resources of The Los Alamos Area New Mexico

By ROY L. GRIGGS

With a section on QUALITY OF WATER

By JOHN D. HEM

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1753

Prepared in cooperation with the Atomic Energy Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library catalog card for this publication appears after page 107.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

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

By Roy L. Griggs

ABSTRACT

The Los Alamos area is in north-central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe. The town of Los Alamos is near the center of the area.

The area, for the most part, lies on the eastern flank of the Jemez Mountains volcanic pile that rests on and rises above the zone of faults at the western margin of the Rio Grande depression. The western edge of the area is near the center of the Jemez Mountains volcanic pile, and from here it extends eastward across a segment of the interior mass of flows and onto an outlying apron of tuff that lies on sedimentary and volcanic rocks belonging to the western part of the Rio Grande depression.

Both the volcanic and the sedimentary rocks are of Late Tertiary and Quaternary age. The volcanic rocks of the Jemez Mountains pile comprise the Tschicoma Formation, Bandelier Tuff, Cerro Toledo Rhyolite, Cerro Rubio Quartz Latite, and Valles Rhyolite. The Tschicoma Formation includes the older interior mass of flows of the volcanic pile, which, within the area, can be divided into two mappable units: (1) latite and quartz latite (older), and (2) pyroxene andesite (younger). The Bandelier Tuff forms the outlying apron of tuff and consists of three members which are, in ascending order, the Guaje, Otowi, and Tshirege Members. The Cerro Toledo Rhyolite, the Cerro Rubio Quartz Latite, and the Valles Rhyolite form volcanic domes within and adjacent to the Valles Caldera, a part of the collapsed interior of the volcanic pile. A body of sedimentary deposits occurs in the Valles Caldera.

The suite of rocks of the Rio Grande depression is included in the Santa Fe Group. This group is represented in the area by three mapped formations. The stratigraphically lowest formation, called in this report the undifferentiated unit of the Santa Fe Group, is a sequence of arkosic sand and silt and some included basalt. Above the undifferentiated unit is the Puye Conglomerate composed chiefly of latitic debris derived from the interior mass of the Jemez Mountains volcanic pile; the Puye also includes some interbedded basalt and a lentil of arkosic conglomerate. The arkosic conglomerate at the base of the formation is the Totavi Lentil of the Puye Conglomerate, and the overlying latitic debris is the fanglomerate member of the Puye Conglomerate. Above the Puye Conglomerate is a local unit of old alluvium. In the eastern part of the area, along the Rio Grande, there is a thick sequence of volcanic rocks referred to in this report as the basaltic rocks of Chino Mesa. These rocks are in part the stratigraphic equivalent of the Puye Conglomerate and the old alluvium.

The stratigraphic units are complexly interrelated as indicated by mapping and subsurface work. The units of the Santa Fe Group interfinger, and the undifferentiated unit and the Puye Conglomerate interfinger with the Tschicoma Formation of the Jemez Mountains volcanic pile.

The volcanic rocks in the Los Alamos area, in general are poor aquifers. Locally, they contain small bodies of perched water, some of which discharge as springs.

The sedimentary rocks are the principal aquifers. The sedimentary rocks in the Valles Caldera area contain several thousand acre-feet of water in storage; and wells that will yield 2,000 gallons per minute or more can be developed in these rocks. The ground-water body of the caldera area, however, maintains the base flow of perennial streams draining the caldera. These surface waters are fully appropriated. Pumping of wells will decrease the associated streamflow and thereby interfere with surface-water rights.

Test drilling in sedimentary rock of the upper 2,000 feet of the undifferentiated unit of the Santa Fe Group in the eastern part of the area led to the discovery of artesian water in a relatively thick series of aquifers. Wells drilled a few hundred feet into the undifferentiated unit of the Santa Fe Group in the Los Alamos area, at places where the altitude of the land surface is less than 5,700 feet, tapped water that flowed to the surface. Data obtained from pumping tests in Los Alamos and Guaje Canyon well fields indicated that the specific capacities of the wells ranged between 3 and 7 gallons per minute per foot of drawdown. The coefficient of transmissibility in the upper 2,000 feet of the undifferentiated unit probably is at least 10,000–12,000 gallons per day per foot.

The dissolved-solids content of ground and surface waters in the Valles Caldera area is less than 150 ppm (parts per million) and chemically the waters are suitable for most uses. Ground water in the Valle Toledo might be objectionable as the sole source for a public water supply because its fluoride content is more than 2 ppm.

Wells in Los Alamos and Guaje Canyon tapping aquifers in the Santa Fe Group yield water containing less than 250 ppm of dissolved solids. The fluoride content of the water from most of these wells is less than 1.0 ppm, however, water from well 14.312 (L6) is more than 2.0 ppm at times. Chemically the water from these wells is suitable for a public water supply.

INTRODUCTION

PURPOSE AND SCOPE

When the town of Los Alamos, N. Mex., was established in the early part of 1943, and on through 1945, the water supply was obtained from small springs and spring-fed streams on the mountain slope west of the town site. By 1945 the town's water requirements had exceeded the amount of water available from these springs and streams, and in 1946–48 six deep wells were completed about 10 miles east of Los Alamos in Los Alamos Canyon, a tributary of the Rio Grande. Shortly thereafter it was anticipated that still additional water supply would be needed by 1951, and in 1948 consideration was given to the development of ground water in the Valles Caldera, a large volcanic depression about 10 miles west of Los Alamos.

In 1949 the U.S. Geological Survey was requested by the Atomic Energy Commission to make a detailed study of the ground water of the Valles Caldera area and to prepare a report describing the availability of water and its relation to the geology. Later the scope of the study was enlarged to include similar studies in the area between the Valles Caldera and the Rio Grande, an area referred to in this report as the "Rio Grande area."

Fieldwork was started in June 1949 and mainly completed by April 1952. During this period a second project, the study of the underground movement of waste products discharged from the Los Alamos laboratory, was started and carried on in conjunction with the water-supply study. The methods and areas of study of these projects were closely related, and personnel were shifted from one project to the other to coordinate activities, particularly in the field of exploratory drilling.

The plan for investigating the availability of ground water included: the mapping of the surface geology; the drilling of test holes; the description and interpretation of drill cuttings from the test holes to determine the location, thickness, relation, and areal extent of various rock units; the identification of the water-bearing rocks; the analyzing of data obtained from pumping tests of wells to determine the hydraulic coefficients of selected aquifers; and the sampling and analyzing of ground waters to determine their chemical quality.

Much work has been done on the geology of the surrounding region and several reports mention a few of the stratigraphic units that are in the Los Alamos area; however, little material dealing specifically with the area has been published. Geologists, who were 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 seventies and deal largely with the regional geology of the country; however, they include Hayden's (1873) original description of the Santa Fe Formation and Cope's (1877) description of the fauna that he and the Wheeler Survey party of 1873 collected from this unit.

Graton (Lindgren and others, 1910) visited the Bland mining district, about 15 miles southwest of Los Alamos, in 1905 and wrote a brief description of the geology and the occurrence of the ore deposits of that district. C. S. Ross made a preliminary investigation of the Valles Mountains (Jemez Mountains) in the 1920's but did not publish a report of his results. A few of the observations of Kirk Bryan (1938) concerning the eastern part of the Los Alamos area are incorporated in a report on the geology and ground-water conditions of the Rio Grande depression. Between 1932 and 1935, Smith (1938) studied and mapped the geology of the Abiquiu quadrangle, whose southern boundary lies a few miles north of Los Alamos. He briefly discussed some geologic units that also are present in the Los Alamos area. Denny (1940) described the Santa Fe Formation of the Espanola area and sedimentary rocks that are exposed at the north end of White Rock Canyon. V. C. Kelley, in connection with pumice studies for the Atomic Energy Commission, prepared a reconnaissance geologic map and a brief report on the Los Alamos area in 1948. This work has not been published.

C. S. Ross and R. L. Smith began a detailed study of the rocks of the Jemez Mountains in 1946. Their study is still in progress. Spiegel and others (1958) have reported on the geology and ground water of the Santa Fe area, about 20 miles southeast of the Los Alamos area.

Quadrangle maps prepared by the Topographic Division of the U.S. Geological Survey on a scale of 1:20,000 and having a contour interval of 20 feet were used as a base for the geologic map. This map was reduced to a scale of 1:31,680 for publication in this report.

ACKNOWLEDGMENTS

Many of the engineering phases of the investigation were made under the supervision of C. V. Theis and C. S. Conover. Messrs. Theis and Conover were actively engaged in some of the pumping tests and made interpretations of most of those tests. R. J. Councill and J. E. Weir, Jr., assisted the writer directly. Mr. Councill was assigned to the project from June 1949 to June 1951, and Mr. Weir was assigned to the project from May 1951 to April 1952.

C. S. Ross and R. L. Smith were engaged in a study of the geology and petrology of the volcanic rocks of the Jemez volcanic pile from 1946 to 1952, and the stratigraphic nomenclature used in this report was mutually agreed upon during a series of discussions in 1952 among the writer, C. S. Ross, and R. L. Smith. The stratigraphic nomenclature is thus the joint product of these men. G. H. Wood aided the writer in compiling the geologic map.

Special thanks are due R. P. Johnson and P. A. Wilson of the Atomic Energy Commission and Richard Crook, L. F. Alexander, and R. E. Armstead of the Zia Co. at Los Alamos.

LOCATION-NUMBERING SYSTEM

Location numbers based on the common system of subdivision of public lands are used in this report to identify the location of wells, seeps, springs, measuring or sampling stations on streams, and other features, the location of which cannot be readily referred to by simpler means. The location number consists of four segments. (See fig. 1.) The first segment denotes the township north of the New Mexico base line; the second segment denotes the range east of the New Mexico principal meridian; the third segment denotes the number of the section within the township; and the fourth segment denotes the subdivisions of the section. The section is considered as being divided into four quarters, numbered 1, 2, 3, and 4 for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment of the location number refers to the appropriate quarter of the section, or 160-acre tract. Similarly, each quarter section is divided into four quarters, or 40-acre tracts. These 40-acre tracts are numbered in the same manner as the 160-acre tracts. The second digit of the fourth segment of the location number refers to the appropriate 40-acre tract. The 40-acre tract is di-

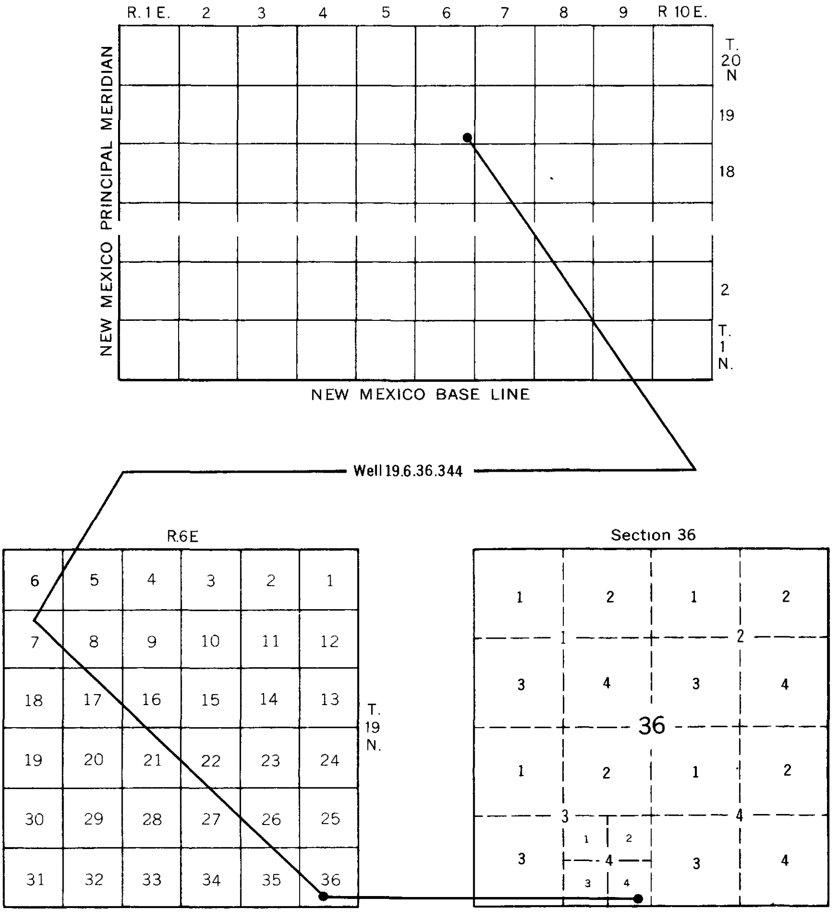

Figure 1.—System of numbering wells and locations in New Mexico.

vided into 10-acre tracts and are numbered in the same manner as the 160- and 40-acre tracts. Thus a location number 19.6.36.344 identifies the location SE¼SE¼SW¼ sec. 36, T. 19 N., R. 6 E.

A zero or zeros may be used in the fourth segment of the location number to indicate that the location of the point is known only to the accuracy of the preceding digit. The fourth segment of the location number is stated even if all three of its digits are zeros.

In the event that the location of more than one point is required within a 10-acre tract, lower case letters a, b, c, * * * are added to the fourth segment to identify the second and succeeding points in that tract.

Wells and springs referred to in the text are numbered on maps in this report by using only the numerals of the fourth segment of the complete location number. Township, range, and section numbers appear elsewhere on the maps to aid the reader in identifying a location when the complete location number is mentioned in the text.

Where several wells or springs are mentioned in a page of text, and all are in the same township, the complete location number is given with the first location mentioned on that page; succeeding locations in that township not separated by the mention of a location in another township are written without the township and range numbers. Thus a reference to several wells might read: Wells 19.6.24.231, 26.242, and 29.342 * * *.

Supply wells and associated test holes in the Guaje and Los Alamos Canyon well fields are known to residents of the Los Alamos area by the following numbering system: Guaje 1 (G1), Guaje 2 (G2), Los Alamos 1 (L1), Los Alamos 2 (L2), * * * are wells 1 and 2 in the Guaje and Los Alamos Canyon well fields, respectively. These numbers in parentheses follow the location number on maps and in the text of this report.

The system of subdivision of the public lands by section, township, and range was extended arbitrarily into the land grant areas to facilitate the location numbering of points within the boundaries of the grants. This extended land net is shown on the maps in this report by dashed lines.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

Los Alamos is in north-central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe (fig. 2). Most of Los Alamos County, the northeastern part of Sandoval County, and the northwestern part of Santa Fe County are included in the Los Alamos area. The length of the Los Alamos

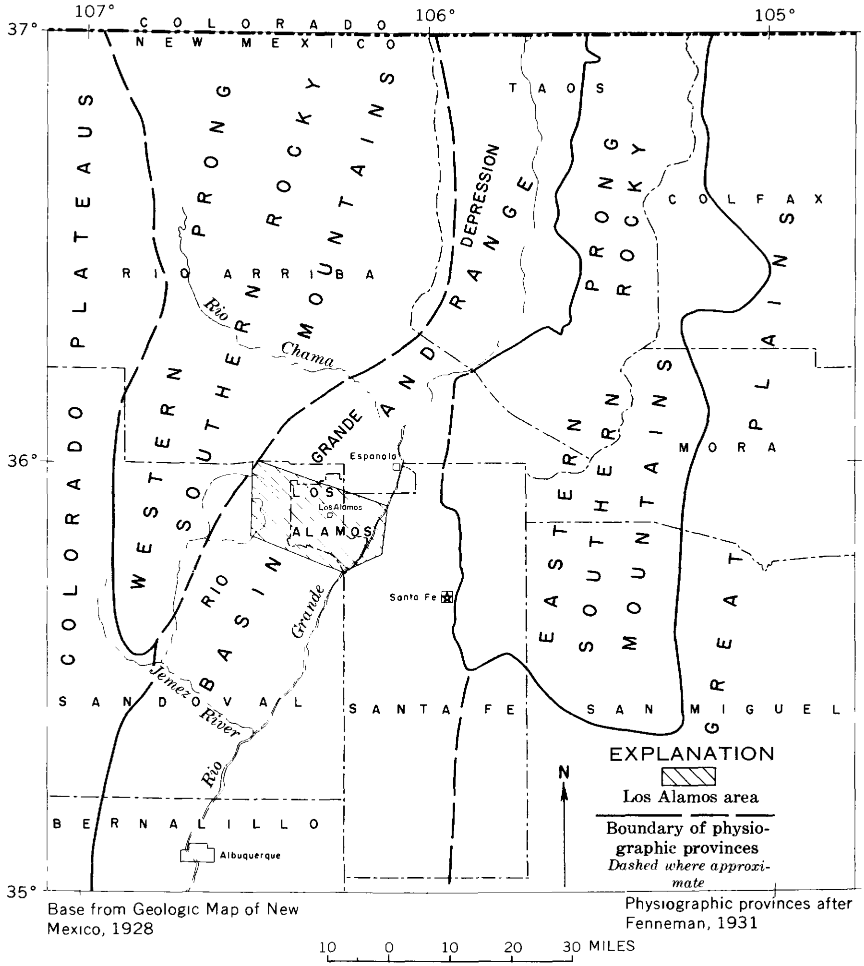

FIGURE 2.—Map of north-central New Mexico showing the location of the Los Alamos area (shaded) and the major physiographic provinces.

area is approximately 20 miles from east to west, and the width is about 10 miles from north to south. Its geographical center is close to long 106°20′ W., lat 35°53′ N.

State Highway 4 crosses the eastern and southern parts of the area. An improved access road leads from State Highway 4 to the headquarters of Bandelier National Monument in Frijoles Canyon at the southern edge of the area.

The town of Los Alamos is the only large community. The village of White Rock, originally built by the Atomic Energy Commission to accommodate the employees of construction contractors, was abandoned. However, it has recently been reactivated, and a number of homes built there by employees of the Los Alamos community. Totavi, formerly a contractor's camp, had only a few residents in 1960. Bandelier National Monument at the southern margin of the area has a few permanent residents.

PHYSIOGRAPHY

REGIONAL SETTING

The Los Alamos area is in a region that includes parts of four main physiographic provinces (Fenneman, 1931). (See fig. 2.) The Southern Rocky Mountains extend southward from Colorado in two north-south prongs, one of which lies east and the other west of the Los Alamos area. Both prongs terminate a short distance south of the latitude of the area. The eastern prong is the Sangre de Cristo Mountains, whose abrupt west front is about 20 miles east of the Los Alamos area (figs. 3 and 4). The western prong is represented by discontinuous mountain masses, the southernmost of which is the Sierra Nacimiento. The axis of this range is about 20 miles west of the Los Alamos area, and its indefinite eastern margin lies a few miles beyond the western margin of the area. The Rio Grande depression, one of the large complex grabens of the Basin and Range province, separates the Sangre de Cristo Mountains and the Sierra Nacimiento.

The Jemez Mountains volcanic pile stands as a circular mountainous element athwart the boundary between the Rio Grande depression and the western prong of the Southern Rocky Mountains (figs. 2 and 5). The volcanic rocks overlap the western prong of the Rocky Mountains and extend eastward into the Rio Grande depression. The volcanic pile consists of a steep-sided interior mass containing a central area of collapse. Discontinuous apronlike plateaus surround the interior mass.

LOS ALAMOS AREA

The Los Alamos area extends westward from the plains and mesas of the Rio Grande depression across a high plateau to the central part of the Valles (Jemez) Mountains.

The Rio Grande is near the eastern margin of the area. The river is fringed on both sides by narrow belts of plains as far south as Otowi bridge (fig. 3 and pl. 1). These plains are relatively flat or gently sloping and are entrenched by shallow arroyos and surmounted by low hills. At the west margin of the plains a fringe of low hills extends westward to the Puye Escarpment, a steep sinuous cliff. South of Otowi bridge, a small plain lies east of the river near the mouth of Canada Ancha.

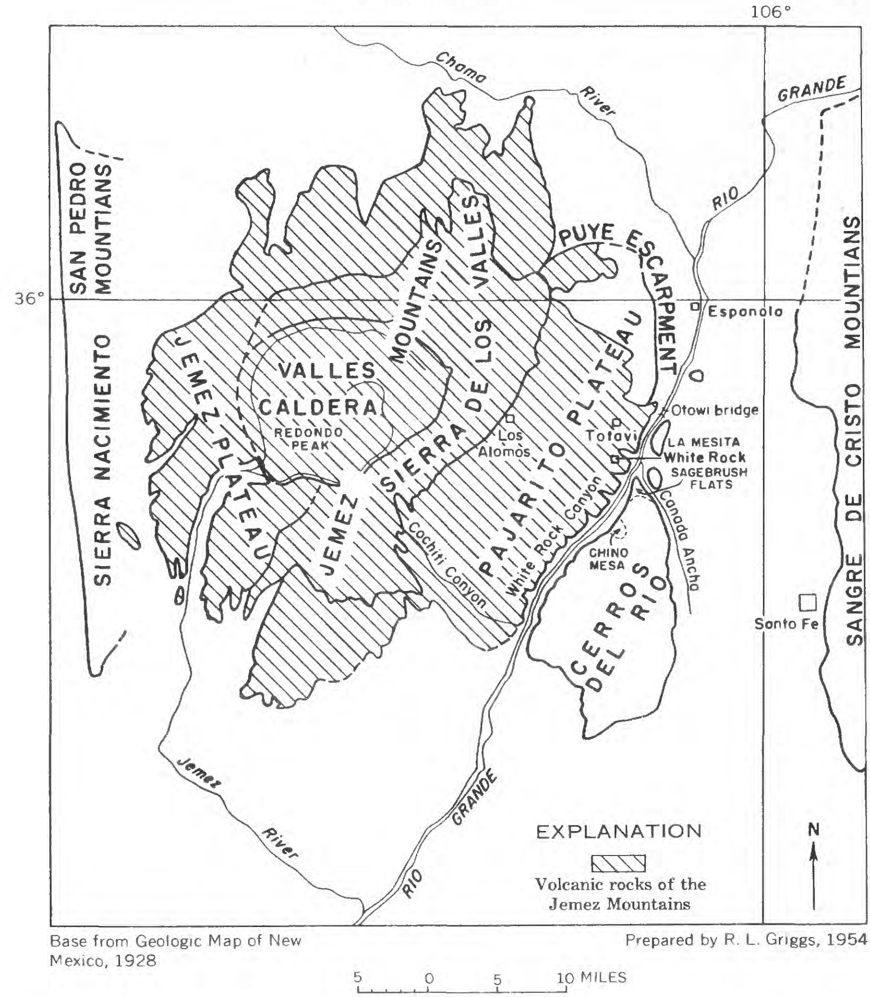

FIGURE 3.—Map showing topographic features in the region of Los Alamos and their relation to the volcanic rocks (shaded) of the Jemez Mountains.

The Rio Grande flows through White Rock Canyon in the southeastern part of the area. Although the west wall of this canyon extends northward to Otowi bridge, the canyon proper starts at the north end of Sagebrush Flats. There the Rio Grande enters a narrow gorge that separates Cerros del Rio (Hills of the River) on the east from the Pajarito Plateau on the west, and the river flows southwestward through the gorge for 14 miles, the entire length of Cerros del Rio. Through this distance the steep canyon walls are about a thousand feet high. A few side canyons, short and abrupt, breach the east wall, and many larger canyons breach the west wall. The eastern

FIGURE 4.—View of the Sangre de Cristo Mountains from the Pajarito Plateau just east of Los Alamos. An outlying remnant of the plateau is in the middle ground.

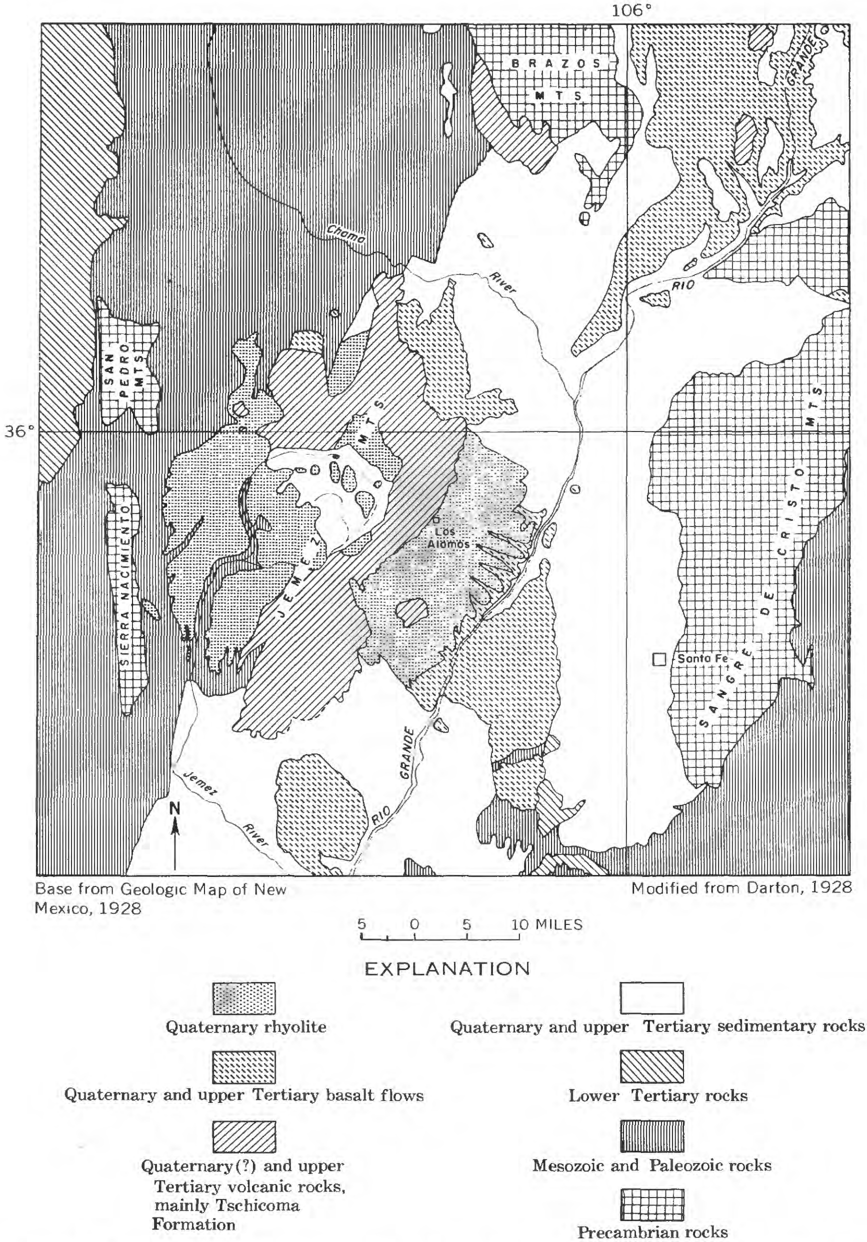

FIGURE 5.—Generalized geologic map of the Jemez Mountains and surrounding region of northern New Mexico.

boundary of the area mapped (pl. 1) extends across part of the Cerros del Rio for about 7 miles, to the axis of the main canyon.

Lying between the Rio Grande and the Sierra de los Valles is a high plateau that Hewitt (1953) called the Pajarito Plateau. He applied the name to "* * * the plateau extending from the Chama River to Canada de Cochiti (Cochiti Canyon) and lying between the Jemez Mountains (Sierra de los Valles) and the Rio Grande." This plateau, capped for the most part, by volcanic tuff extends for more than 30 miles parallel to the Rio Grande and is one of the prominent volcanic plateaus that surround the Sierra de los Valles (fig. 6). The surface of the plateau was originally continuous, but now it is dissected by many narrow, steep-walled canyons, 200–400 feet deep, cut through the tuff cap by intermittent streams that drain from west to east across the plateau. As a result the country is characterized by long fingerlike mesas between the canyons. The upper surfaces of the mesas rise gently to the west and abut against the Sierra de los Valles. These elongate steep-sided mesas are known locally as potreros. The rugged terrain, difficult of access because of the narrow entrenched canyons between the potreros, was inhabited by prehistoric Indians who apparently liked the natural protection afforded by the rough country. Ruins of cliff dwellings in the canyon walls and house ruins on the tops of the potreros are numerous and were made famous by the ethnologist, Adolph Bandelier.

The steep irregular slopes immediately west of the Pajarito Plateau are part of the crescent-shaped Sierra de los Valles. The Sierra rises abruptly from the plateau and culminates in a group of serrate peaks and saddles. This mass has been severely eroded and decapitated.

The Valles Caldera (only its eastern half is included in the mapped area) lies directly west of the Sierra de los Valles. This caldera is nearly circular and is delineated by the curving drainage pattern of the East Fork of Jemez River at the south and San Antonio Creek (a tributary of Jemez River) at the north and west. The diameter of the caldera is about 12 miles. Its outer margin is marked by a steep inward-facing escarpment whose upper limit is the curving crest of the Sierra de los Valles (fig. 7). The floor of the caldera is grass covered and lies from about 500 to nearly 2,000 feet below the surrounding rim. This floor is studded with numerous moundlike volcanic domes that divide the depression into a network of valleys. The tops of some of the domes are as much as 1,500 feet above the floors of the valleys, and Redondo Peak (west of the area mapped) is a large mountain whose top is about 2,600 feet above the valleys.

FIGURE 6.—View of the Jemez Mountains volcanic pile from the western foot of the Sangre de Cristo Mountains. The interior mass of the volcanic pile is on the horizon, and the Pajarito Plateau is at the base of the steep slopes. Badlands of the Rio Grande Valley are in the foreground.

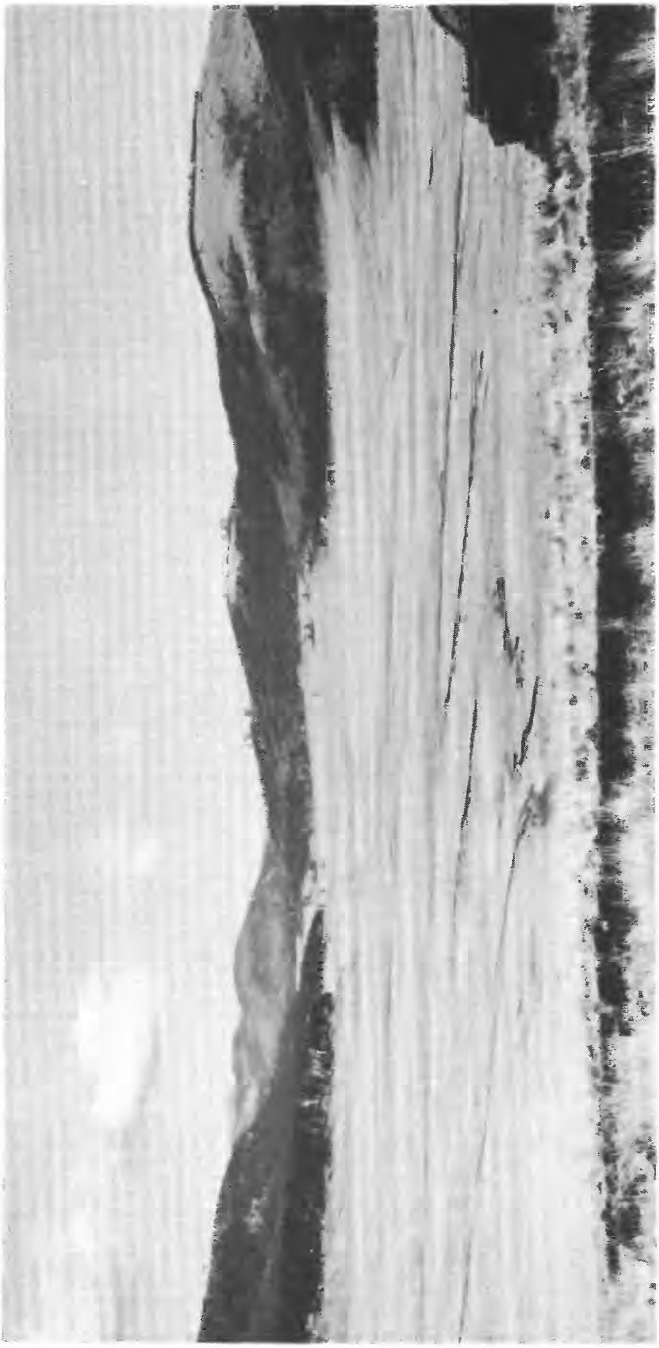

FIGURE 7.—View northward across eastern part of the Valles Caldera. The high peaks on the right are on the crest of the Sierra de los Valles. The forested mound on the left is rhyolite dome within the caldera.

TOPOGRAPHY AND DRAINAGE

Altitudes in the Los Alamos area range from 5,360 to 10,920 feet above sea level. The lowest altitude is at the extreme southeast corner of the area at river level in White Rock Canyon. Farther north, in the east-central part of the area, the altitude of the river is about 5,500 feet. The Pajarito Plateau to the west has a southeastward slope and is mainly between 6,400 and 8,000 feet above sea level. Some peaks along the Sierra de los Valles west of the plateau are more than 10,000 feet high, such as Pajarito Mountain, 10,441 feet; Cerro Rubio, 10,449 feet; Caballo Mountain, 10,496 feet; Cerro Toledo, 10,920 feet, and Turkey Ridge, 10,676 feet. Altitudes in the caldera (within the area) range from about 8,500 feet on the floor to 10,332 feet at the top of Cerro del Abrigo, one of the central domes.

The rim of the caldera forms a surface-water divide. Streams heading on the east slope of the Sierra de los Valles and on the Pajarito Plateau follow courses almost directly eastward to the Rio Grande. The Rito de los Frijoles, however, is the only stream that flows perennially into the Rio Grande. Other streams in the area flow perennially for short distances beyond the east margin of the Sierra de los Valles, but these flows are either intercepted on the lower slopes of the mountain and diverted into the Los Alamos town system, or infiltrate into their channel beds during dry weather. Streams that head within the caldera flow westward and southward to the southwest part of the caldera. Two main streams drain the caldera. The southern part is drained by the East Fork of the Jemez River, and the northern part is drained by San Antonio Creek. These two curving streams combine west of the area to form the Jemez River which, after following a circuitous course around the southern side of the volcanic pile, flows to the Rio Grande.

CLIMATE AND VEGETATION

The climate is generally semiarid, but it varies greatly from the eastern to the western parts of the area. The average annual precipitation is only about 10 inches on the plains adjacent to the Rio Grande. It increases to about 15 inches at Bandelier National Monument headquarters in the southern part of the Los Alamos area and to about 18 inches at the west margin of the Pajarito Plateau. Precipitation in the high parts of the mountains probably averages at least 20 inches annually.

The heaviest precipitation occurs during local storms in late spring and summer. Approximately three-fourths of the annual precipitation is concentrated in the 6-month period from April through September, and generally about $\frac{1}{3}$–$\frac{1}{2}$ of the annual precipitation is concentrated in a rainy season in July and August when the local storms are most frequent. Snowfall is light on the plains but is about 50 inches annually at the west edge of the plateau and may be as much as 100 inches in the higher parts of the mountains. State Highway 4 generally is blocked by snow in the higher parts of the mountains from the latter part of November through February or March.

Temperatures vary with altitude. The average July temperature at lower altitudes is about 75°F and about 67°F at Los Alamos. The average January temperature at Espanola is about 29°F and 27°F at Los Alamos. A 2-year record (1949–50) of temperatures in the Valles Caldera indicated an average July temperature of about 54°F and an average January temperature of about 15°F.

The types of vegetation vary with altitude and exposure. The plains of the northeastern part of the area are a semidesert grassland having vegetation of the upper Sonoran type. The grasses are three-awns, some sacaton and galleta, and lesser amounts of gramma. Sagebrush and rabbit brush are fairly abundant, and cane cactus and prickly pear are common. The trees include scattered piñon and juniper, and cottonwoods and willows are abundant along the Rio Grande. The Pajarito Plateau has a woodland pasture 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. Ponderosa pine is abundant mainly above 7,000 feet, but along canyons of the plateau, particularly on north slopes, it grows at altitudes as low as 6,200 feet. The slopes of the Sierra de los Valles are covered by a pine and 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 8,000 feet. Spruce is abundant on the highest parts of these slopes, and dense groves of aspen grow where the conifers have been burned in forest fires in times past. The wide valleys that form the floor of the Valles Caldera are lush grasslands covered with fescues, bunch grass, and some sedges. Even bluegrass grows locally. The escarpment and the steepsided interior domes of the caldera support the growth of some Ponderosa pine which is commonly conspicuous along the southern and eastern margins of the domes, but these areas are covered mainly by a dense forest of spruce and fir that contains numerous groves of aspen.

GEOLOGY

STRATIGRAPHY

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 Cristo Mountains to the east, in the Brazos Mountains to the north, and in the Sierra, Nacimiento, and San Pedro Mountains to the west (fig. 5). These Precambrian rocks, consisting of granite, gneiss, schist, and quartzite, have been downfaulted to great depth in the Rio Grande depression. In the Los Alamos area their upper surface may lie below sea level. Sandstone and limestone of the Arroyo Penasco Formation of Mississippian age (Fitzsimmons, and others, 1956) rest unconformably on Precambrian rocks in the Sierra Nacimiento. The Magdalena Group of Pennsylvanian and Permian age overlies the Arroyo Penasco Formation. This group, consisting of limestone, shale, and sandstone, is exposed a few miles west of the Los Alamos area, just beyond the western margin of the Rio Grande depression (Wood and Northrop, 1946); hence, at least part of the group probably underlies the Los Alamos area. Similarly, beds of sandstone and shale of the overlying Abo Formation of Permian age probably underlie the area. Younger rocks, ranging in age from Permian through Cretaceous, crop out in the Sierra Nacimiento area and in the southern and northwestern parts of the Jemez Mountains; thus, they probably underlie the eastern part of the Los Alamos area. Paleozoic and Mesozoic rocks younger than the Abo Formation probably were removed by erosion from the Los Alamos area prior to middle Tertiary time, but some early Tertiary sedimentary rocks and possibly some early Tertiary igneous rocks may underlie the Santa Fe Group in the area.

The late Tertiary and Quaternary volcanic and sedimentary rocks that crop out in the Los Alamos area are associated with the Rio Grande depression, an extensive fault trough which originated in middle Tertiary time and along which intermittent faulting has continued into Recent time. The rocks of the Jemez Mountains volcanic pile were erupted from feeders along faults at or near the western boundary of the Rio Grande depression. The specific site of the eruptions is at a bend in the strike of thes faults, where strike-slip movement has allowed tensional opening. The western edge of the Los Alamos area is near the center of the collapsed interior of the volcanic pile. From there the area extends eastward across a segment of the interior mass of flows, an outer apron of tuff, and onto a group of sedimentary and volcanic rocks that accumulated within the west-central part of the Rio Grande depression. The area of outcrop of these rocks of Tertiary and Quaternary age are shown on the geologic map of the Los Alamos area on plate 1. The general stratigraphic relations of these younger rocks are shown in figure 8.

Rocks of the Jemez Mountains volcanic pile of late Tertiary and Quaternary age consist of an older sequence of flow rocks, the Tschicoma Formation of Pliocene and Pleistocene(?) age, and younger tuff and extrusive domes of the Tewa Group of Pleistocene age. The

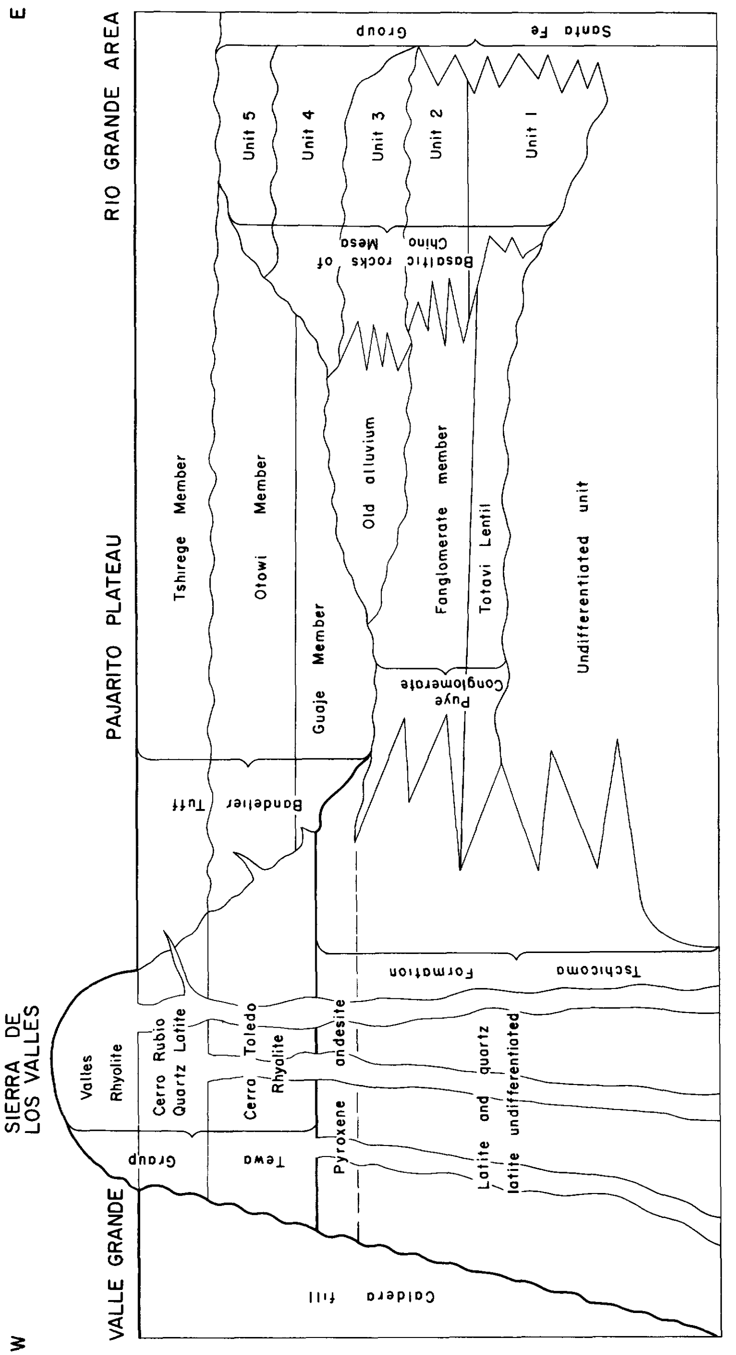

FIGURE 8.—Chart showing generalized stratigraphic relation of main map units in the Los Alamos area.

Tschicoma Formation is divisible into two units. The older unit, composed of thick flows of gray to purplish-gray latite and quartz latite, forms the greater part of the Sierra de los Valles. The younger unit, composed of flows of dark-gray pyroxene andesite, crops out in one small area on the Sierra de los Valles and is present in places in the subsurface beneath the Pajarito Plateau. Locally, the Tschicoma Formation is more than 2,600 feet thick.

The Tewa Group includes four main units: the Bandelier Tuff, the Cerro Toledo Rhyolite, the Cerro Rubio Quartz Latite, and the Valles Rhyolite. The Bandelier Tuff, composed of light-gray to buff-colored tuff, caps the Pajarito Plateau and has been divided into three lithologic units: the Guaje, Otowi, and Tshirege Members, named in ascending order. This entire tuffaceous sequence ranges in thickness from about a hundred to about a thousand feet. It is in part of ash-fall origin but is composed mainly of ash flows. The Cerro Toledo Rhyolite, the Cerro Rubio Quartz Latite, and the Valles Rhyolite constitute the volcanic domes in and adjacent to the Valles Caldera. In addition to the above igneous rocks, thick lacustrine deposits that are overlain by terrace deposits and alluvial fans crop out in the Valles Caldera. These unconsolidated Caldera sediments range in age from Pleistocene to Recent.

The suite of sediments and volcanic rocks that accumulated in the interior of the Rio Grande depression is referred to the Santa Fe Group of middle(?) Miocene to Pleistocene(?) age. This group includes three main units: an undifferentiated unit, the Puye Conglomerate, and the basaltic rocks of Chino Mesa. The undifferentiated unit of Miocene and Pliocene age is a sequence of salmon-colored poorly consolidated beds of arkosic sand, silt, and clay and local gravel lenses that crop out between the Sangre de Cristo Mountains and the Pajarito Plateau. Basalt is interbedded locally. Most of these sediments were derived from rocks bordering the depression on the east but some fragments, chiefly in the subsurface, were derived from the latitic flows of the Tschicoma Formation. The thickness of the unit is unknown. Wells drilled 2,000 feet into the formation did not reach its base.

The Puye Conglomerate of late Pliocene(?) age is exposed along the Puye Escarpment (fig. 3), White Rock Canyon, and some of the canyons of the Pajarito Plateau. The formation consists of two members. The Totavi Lentil, which is the lower member, is a poorly consolidated conglomerate as much as 75 feet thick and composed of fragments that were derived from a Precambrian terrane and deposited in a large stream channel. The upper member is a fanglomerate composed of latitic debris derived from the Tschicoma Formation, and it ranges in thickness from 0 to about 600 feet.

The basaltic rocks of Chino Mesa are of late Pliocene(?) and Pleistocene age and are exposed on both sides of White Rock Canyon. These rocks are more than 1,000 feet thick in places. The sequence has been differentiated on the basis of composition and form of extrusion into five unnamed units.

A local unit of old alluvium is closely associated with the middle unit of basaltic rocks of Chino Mesa.

The Santa Fe Group and the Jemez Mountains volcanic rocks accumulated during the formation of the Rio Grande depression, and the various stratigraphic units of the area are interrelated. Stratigraphic relations of the main units are shown in figure 8.

ROCKS OF THE RIO GRANDE DEPRESSION

SANTA FE GROUP

The main part of the fill of the Rio Grande Valley between Espanola and Santa Fe was called originally the Santa Fe Marl by Hayden (1873, p. 166–168), 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 * * *." Although Hayden described materials as being as coarse as "puddingstone," he called the alluvial material marl because the view was prevalent at the time that the sedimentary deposits of all the fault-trough basins of the Western United States were lake deposits. Johnson (1904) and later workers demonstrated that these poorly consolidated rocks were mainly alluvial, and the name was changed to Santa Fe Formation. As more became known of the general character of the rocks of the Rio Grande depression, the name was extended to include most of the sedimentary filling of the fault trough. Bryan (1938, p. 205) described the Santa Fe Formation as being "* * * the main body of sedimentary deposits of the Rio Grande depression, from the north end of the San Luis Valley [Colo.] to and beyond El Paso [Tex.] * * *." The rank of the unit was raised to that of group (Spiegel and others, 1958) in order to include other stratigraphic units that are related to the filing of the Rio Grande depression.

The Santa Fe Group of this report includes three main units: (1) an undifferentiated unit, largely arkosic debris; (2) the Puye Conglomerate, largely a fanglomerate derived from the Tschicoma Formation; and (3) the basaltic rocks of Chino Mesa.

UNDIFFERENTIATED UNIT

Definition

The undifferentiated unit of the Santa Fe Group is the body of salmon-colored slightly consolidated sedimentary deposits that crop out from the Sangre de Cristo Mountains to the Pajarito Plateau. As defined in this report, the undifferentiated unit generally is the same as the Santa Fe Formation of Bryan (1938) and probably mostly equivalent to the Tesuque Formation of Baldwin and Kottlowski (in Spiegel and others, 1958). The terminology of Baldwin and Kottlowski, however, is not used in this report because the Tesuque Formation and the Ancha Formation of Baldwin and Kottlowski cannot be differentiated lithologically in the Los Alamos area. The main body of the undifferentiated unit in the Los Alamos area probably is mainly equivalent to the Tesuque Formation, though the uppermost part of the tongue of the undifferentiated unit, locally present at the north end of Sagebrush Flats, may be equivalent to the Ancha Formation.

Distribution and Thickness

The undifferentiated unit is exposed in the eastern part of the area and, as indicated by well cuttings, is present in the subsurface beneath a large part of the Pajarito Plateau. Exposures extend northward along White Rock Canyon from near the mouth of the Rito de los Frijoles. As the top of the unit rises topographically to the north, exposures extend high on the slopes of the Puye Escarpment and westward into the lower reaches of Los Alamos and Guaje Canyons. Good outcrops are discontinuous in this belt of exposures. The outcrops 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 unit is masked by Quaternary alluvium in the Rio Grande Valley north of Otowi bridge. Only the uppermost part of the undifferentiated unit is exposed in the Los Alamos area, and this part is about 500 feet thick. Well 19.7.4.444 (G1) in Guaje Canyon (fig. 9) penetrated 2,025 feet of the unit without reaching the base; thus, the total thickness is not known.

Lithology

The undifferentiated unit is composed mainly of beds of silty sand and sandy silt that range from pinkish gray to grayish pink to pinkish buff. Beds of gravel and conglomerate—usually silty and sandy—are common, particularly near the east side of the Rio Grande depression. Beds of clay are not uncommon, but generally they are only a few feet thick. Basalt flows and breccia are interbedded in places as in the subsurface in Guaje Canyon. The upper part of the undifferentiated unit contains gravel and boulders that were derived from volcanic rocks. The gravel and boulders are interbedded with silt and sand similar to that of the underlying main body of the unit. In general, the sediments of the undifferentiated unit are poorly consolidated, although some beds are moderately indurated. The cementing material is calcium carbonate.

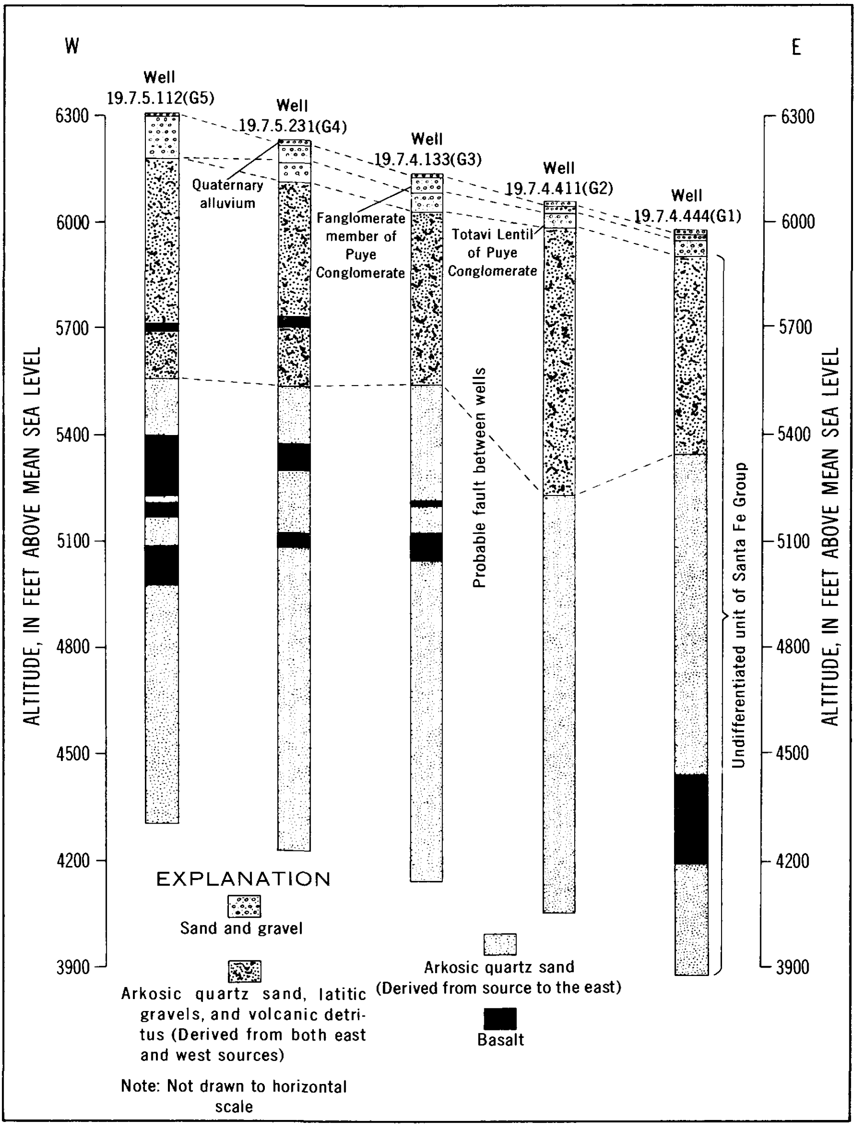

FIGURE 9.—Graphic logs of wells showing the correlation of beds penetrated in the Guaje Canyon well field.

The sand consists mainly of quartz and feldspar but some grains are yellow to pink chalcedonic silica. The quartz particles are colorless, yellow, and pink. The feldspar is mainly pink microcline, but some colorless feldspar is present, some of which is plagioclase and some of which is sanidine. Dark minerals are scarce in the finer sands, but the finer fractions of many of the coarser sands contain dark minerals in small quantities. The dark minerals consist chiefly of biotite and hornblende though some clinopyroxene also is present. The gravel is composed mainly of quartz, pink microcline, and granitic rocks. Pebbles of volcanic rocks ranging in type from andesite to rhyolite are not uncommon, particularly in the upper part of the unit. Some pebbles are quartzite and schist and a few are limestone. The mineralogy of the silt and clay particles has not been studied, but most of the silt is probably quartz and feldspar, and the clay is probably a montmorillonite type.

Sorting is poor and variations in texture are abrupt, both vertically and horizontally. Bedding is indistinct in the coarsest sedimentary deposits. A faint or irregular stratification is fairly general, although some coarse deposits show no horizontal bedding. Cross-lamination, however, is fairly common, particularly in some of the better sorted sands (fig. 10), and lenses of coarse grains in beds of finer material are common. Horizontal bedding can be seen in the clays, sandy silts, and some of the very silty, fine-grained sand (fig. 11). This bedding is indistinct at some exposures and fairly distinct at others. Cross-lamination generally is absent in the finer grained sediments. The bedding and the fineness of the grains indicate that these fine-grained rocks were deposited on flat-lying surfaces, probably on an alluvial plain that was beyond the margin of alluvial-fan deposition.

The undifferentiated unit of the Santa Fe Group contains basalt flows and breccia (fig. 9). Well 19.7.5.112 (G5) in Guaje Canyon penetrated 346 feet of flows and breccia between the depths of 595 and 1,327 feet, or between 468 and 1,200 feet below the top of the undifferentiated unit. These flows of basalt thin and disappear eastward. Well 4.411 (G2), 1½ miles southeast of well 5.112 (G5) penetrated no basalt; however, 250 feet of basaltic breccia was penetrated in a single sequence in well 4.444 (G1). These rocks, between 1,465 and 1,715 feet below the top of the undifferentiated unit, are believed to have flowed from a nearby buried vent. A single basalt flow is exposed in White Rock Canyon about 200 feet below the top of the unit. These basalt flows are all much alike. They are dark gray to almost black where fresh and reddish brown where they are brecciated and somewhat altered by oxidation. All the specimens of basalt examined microscopically contain tiny phenocrysts of olivine, more or less completely altered to iddingsite or a combination of iddingsite and a high iron saponite (C. S. Ross, oral communication, 1951), in a 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 are close to An_{30}. The two highest flows

FIGURE 10.—Cross-laminated sandstone of the undifferentiated unit of the Santa Fe Group, Los Alamos Canyon.

FIGURE 11.—Siltstone of the undifferentiated unit of the Santa Fe Group showing horizontal bedding, Los Alamos Canyon.

penetrated by well 5.112 (G5) contain xenocrysts of plagioclase that have a motheaten appearance. These xenocrysts of plagioclase are identical in composition with xenocrysts in the latitic flows of the Tschicoma Formation.

Westerly derived material has been noted at surface exposures at only one locality. Near the mouth of Ancho Canyon, just west of White Rock Canyon, the uppermost 200 feet of the undifferentiated unit contains beds of gravel and boulders derived from the Tschicoma Formation to the west, and some beds show arkosic sand derived from the east intermixed with gravel and boulders derived from the Tschicoma Formation to the west. Thus this 200-foot interval at this locality, directly underlying the Totavi Lentil of the Puye Conglomerate, shows an interfingering and intermixing of easterly and westerly derived alluvial-fan elements. The easterly derived sand is typical of that of the unit, and the westerly derived material is latitic material typical of the Tschicoma Formation.

Westerly derived materials are very conspicuous in the subsurface in Guaje Canyon where they are interbedded and intermixed with easterly derived materials, showing a very striking interfingering and intermixing of easterly and westerly derived fan elements. The westerly derived materials are most abundant at well 19.7.5.112 (G5), the westernmost well in the canyon, and least abundant at well 4.444 (G1), the easternmost well in this canyon. At well 5.112 (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 Formation that crops 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 some pebbles of porphyritic rocks that must have been derived from the Tschicoma Formation. All these westerly derived materials decrease in amount to the east, and in well 4.444 (G1) only a few beds in the upper 560 feet of the unit contain pebbles of latitic material derived from the Tschicoma Formation. One thin bed at this well is composed entirely of Tschicoma derived material. (See fig. 9.)

Contacts With Adjacent Rocks

The correlation of rocks beneath the undifferentiated unit in the Los Alamos area is a matter of conjecture. The Abiquiu Tuff of Smith (1938) underlies the Santa Fe Formation of Smith (1938, p. 955) in the Abiquiu quadrangle north of Los Alamos. Cabot (1938, p 91–93) found his 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. The Picuris Tuff of

Cabot and the Abiquiu Tuff of Smith, believed to be correlative, may form a nearly continuous unit at the base of the Santa Fe Group in the Rio Grande depression in the latitude of the Los Alamos area. The Santa Fe Group in the surrounding region generally rests conformably on the Abiquiu Tuff or Picuris Tuff, although the contact is unconformable locally. In turn, the Abiquiu and Picuris Tuff probably are separated from the Precambrian at places in the depression by Paleozoic, Mesozoic, and early Tertiary sedimentary and igneous rocks.

The upper part of the undifferentiated unit of the Santa Fe Group in the Los Alamos area is related in a complex way to the Puye Conglomerate, the basaltic rocks of Chino Mesa, and the Tschicoma Formation. The Totavi Lentil of the Puye Conglomerate rests unconformably on the undifferientiated unit along the Puye Escarpment and along part of White Rock Canyon; however, in White Rock Canyon in the southernmost part of the area, the Totavi Lentil interfingers with the basalt of unit 1 of the basaltic rocks of Chino Mesa, and the undifferentiated unit is overlain unconformably by unit 1 of these basaltic rocks. The Totavi Lentil rests on the main body of the undifferentiated unit at Sagebrush Flats on the north end of the Cerros del Rio, where the Totavi Lentil is overlain by an upper tongue of the undifferentiated unit. This tongue is largely equivalent to the lower part of the fanglomerate member of the Puye Conglomerate, but it is similar lithologically to the undifferentiated unit. The uppermost part of the tongue of the undifferentiated unit probably is equivalent to the Ancha Formation (Spiegel and others, 1958). Two miles south of the northern end of Sagebrush Flats the upper tongue of the undifferentiated unit wedges out by interfingering into units 1 and 2 of the basaltic rocks of Chino Mesa. The Totavi Lentil persists for more than 2 miles to the south of this point before it wedges out.

The part of the undifferentiated unit that contains debris from the Tschicoma Formation interfingers with flows of the Tschicoma in the subsurface in the western part of the Pajarito Plateau.

Age

The first vertebrate fossils collected from the sediments of the valley came from near San Ildefonso, just northeast of the Los Alamos area and 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 collected additional specimens from the same locality. Cope collected fossils representing 31 species of vertebrates from this locality in 1874. Cope (1877, p. 364) concluded that the fauna of the sedimentary rocks of the valley "* * * more nearly resembles the upper Miocene of Europe than the Pliocene of that continent." Osborn (1909, p. 65) assigned the same sequence to the late Miocene, but later he (Osborn, 1918, p. 34) decided that the lower part of the sequence was transitional into the Pliocene and that the upper part was early Pliocene in age. Frick (1933, p. 549) stated that,

> * * * recent investigation indicates that the accumulations of this portion [Espanola-Santa Fe area] of the Rio Grande basin ranges from the Mid-Miocene to Pleistocene. The Pleistocene occurs in remnants of eolian origin that here and there cap the irregular Pliocene-Miocene surface.

More recent investigations by Frick and others apparently indicate that the undifferentiated unit of the Santa Fe Group of the immediate region ranges in age from about middle Miocene to middle or upper Pliocene (Frick, 1937; Wood and others, 1941, p. 31).

PUYE CONGLOMERATE

Definition

The name Puye (pronounced poo-yay) Gravel was used by Smith (1938, p. 937) as a formation name in the explanation of his map of the Abiquiu quadrangle, an area a few miles north of the Los Alamos area. Smith stated (1938, p. 949) that the new formation would be described in a forthcoming publication, but this description has not appeared, and no type locality was specified for the formation. A thick unit of conglomerate, cropping out in Guaje Canyon and along the Puye Escarpment in the Los Alamos area was traced northward into the Abiquiu quadrangle and is equivalent to the Puye Gravel as mapped by Smith. The name Puye Conglomerate is used for these rocks in this report because the formation is sufficiently consolidated to stand in vertical cliffs.

The Puye Conglomerate, as mapped in the Los Alamos area, is best exposed in Guaje Canyon and near the southern end of the Puye Escarpment where it has been eroded to form steep slopes and cliffs. The type locality is herein designated as the belt of exposures along Guaje Canyon between Guaje Mountain and the Puye Escarpment. J. E. Weir, Jr., and W. D. Purtymun measured a stratigraphic section of the formation in the NW¼NE¼SW¼ sec. 11, T. 19 N., R. 7 E., near the outer edge of the unit. A detailed description of this section is given on page 33, and a graphic section is shown on plate 1. At the site of this section the Puye Conglomerate is 232 feet thick, but it thickens westward, toward the Sierra de los Valles. The thickest known section is in a test hole in Pueblo Canyon (19.6.14.221). Here the unit is 726 feet thick.

The lower part of the formation consists of gravel composed of well-rounded pebbles, cobbles, and small boulders of quartzite, quartz, granite, and some volcanic debris in a matrix of fine- to coarse-grained arkosic sand. This unit, ranging from 0 to about 80 feet thick, is here named the Totavi Lentil of the Puye Conglomerate. This lentil rests with angular unconformity on the undifferentiated unit of the Santa Fe Group. The upper part of the Puye, above the Totavi Lentil, is here informally called the fanglomerate member of the Puye Conglomerate. Fragments of volcanic rocks of latitic composition form most of the detritus of this thick fanglomerate member. Beds of latitic pumice also are present, and there is some included basalt.

Distribution and Thickness

The Puye Conglomerate is of local extent. It is present only on the east side of the Sierra de los Valles where it lies adjacent to the latitic rocks of the Tschicoma Formation. The strip occupied by the formation as known at the surface and in the subsurface is about 10 miles wide, and exposures extend about 15 miles in a north-south direction, from the latitude of Espanola southward into the Los Alamos area. The Puye probably is present in the subsurface for several miles south of the area of exposures, although here its east-west extent probably is fairly narrow. South of Los Alamos Canyon the deposition of the Puye Conglomerate was restricted at the east because of the synchronous outpouring of lava flows of the lower units of the basaltic rocks of Chino Mesa from centers in the Cerros del Rio. The Totavi Lentil in the southern part of the area in White Rock Canyon interfingers with basalt flows and is not a distinct unit south of the mouth of Ancho Canyon. The Puye Conglomerate at the north end of White Rock Canyon is only 60–80 feet thick. The formation thickens northward and westward on the Pajarito Plateau. The maximum known thickness is at well 19.6.14.221 in Pueblo Canyon, where the unit, including both members, is about 725 feet thick. It is 220–270 feet thick along the east edge of the Puye Escarpment. The thickness near the mouth of Guaje Canyon is 232 feet. In roadcuts along State Highway 4 in sec. 15, T. 19 N., R. 7 E., near Totavi it is about 155 feet thick.

Totavi Lentil

The Totavi (pronounced To-tah-vee) Lentil of the Puye Conglomerate is here named for the community of Totavi in the eastern part of the area. The gravel of the lentil is excavated from a quarry near Totavi and used for concrete aggregate. The quarry designated as the type locality of the lentil is just north of State Highway 4 and about a quarter of a mile west of Totavi in the NW¼SE¼SE¼ sec. 15, T. 19 N., R. 7 E. The base of the lentil is not exposed at the quarry, but it is well exposed north of Totavi where the lentil rests with erosional unconformity on the undifferentiated unit of the Santa Fe Group. The Totavi Lentil at the quarry is about 58 feet thick and is overlain conformably by the fanglomerate member of the Puye.

The Totavi Lentil is a poorly consolidated conglomerate composed of material ranging from fine-grained sand to boulders more than 1 foot in diameter. The sand, composed mainly of quartz and microcline, occurs as lenses and as an interstitial filling between the larger particles. The gravel and boulders are composed chiefly of quartzite, granite, and pegmatitic rocks derived from a Precambrian terrane. Some fragments are volcanic rocks that are foreign to the area, and a few boulders are composed of rocks from the Tschicoma Formation.

The following section of the Totavi Lentil was measured in the gravel quarry north of State Highway 4 on the north side of Los Alamos Canyon. The quarry is in the NW¼SE¼SE¼ sec. 15, T. 19 N., R. 7 E., about a quarter of a mile west of Totavi. The section was measured by J. E. Weir, Jr., and W. D. Purtymun, April 28, 1960, and is shown graphically (section A) on plate 1.

Top of section.

	Thickness (feet)
Puye Conglomerate	
Fanglomerate member (in part):	
4. Conglomerate	20+
3. Siltstone, light-gray to light-brown; probably formed of tuffaceous material, forms ledge in upper part of quarry. Bed is well consolidated and may be calcareous where it forms a hard ledge. Near the west side of quarry the bed is almost as friable as the underlying Totavi Lentil. Bed was deposited on an irregular surface and appears to interfinger with the upper gravels of the Totavi Lentil	3+
Totavi Lentil:	
2. Conglomerate, containing interbedded interfingering sand lenses and thin siltstone beds; friable but stands as a cliff in the quarry wall. Individual lenses truncate other lenses. Upper 30–40 ft contains black stringers of carbonaceous(?) material. Sands are composed predominantly of granitic detritus. In Bayo Canyon, a short distance to the north, the Totavi Lentil is only 20 ft thick. Base of unit is very poorly exposed and covered at places	53±
Undifferentiated unit (in part):	
1. Clay, tan to brown, silty and sandy. Upper surface of clay is slightly irregular but may be a westward-sloping bench of old streambed	5+

Base of section.

Exposures of the Totavi Lentil extend from several miles north of the Los Alamos area southward to the junction of White Rock and Ancho Canyons in the southeastern part of the area. Good exposures are nearly continuous along the Puye Escarpment and in Los Alamos and Guaje Canyons, where the lentil crops out along a topographic break between the relatively steep slopes formed on the underlying undifferentiated Santa Fe and vertical cliffs formed by the overlying fanglomerate member of the Puye Conglomerate.

The lentil in the west wall of White Rock Canyon is poorly but continuously exposed to immediately south of Ancho Canyon, where it interfingers with beds of basalt and poorly consolidated sediments of the lowest unit of the basaltic rocks of Chino Mesa. Beyond this point it could not be differentiated from enclosing basalt flows. Thin wedges of the lentil pinch out eastward on the east side of the Rio Grande.

Drill cuttings from the Totavi Lentil were obtained from several wells and test holes west of the outcrop areas. The lentil was penetrated by four wells in Guaje Canyon, but it pinches out between wells 19.7.5.231 (G4) and 5.112 (G5) in this canyon. It was penetrated also by well 22.114 (L4) in Los Alamos Canyon and by test holes 19.6.13.344, 14.221, and 19.7.20.221 farther west in Los Alamos and Pueblo Canyons. As indicated by cuttings from test hole 19.6.17.234 in Los Alamos Canyon, it is interbedded between two quartz latite flows of the Tschicoma Formation. The Totavi Lentil thickens northwestward from its area of wedgeout in White Rock Canyon and is about 88 feet thick at test hole 19.6.14.221 in Pueblo Canyon.

The Totavi Lentil is nonconformable with the underlying undifferentiated unit of the Santa Fe Group at some places and disconformable at other places. The lentil in the northeastern part of the area is overlain conformably by the fanglomerate member of the Puye Conglomerate. At the northwest tip of Sagebrush Flats, it is overlain conformably by arkosic sedimentary rocks of the upper tongue of the undifferentiated unit of the Santa Fe. It is overlain by and interfingers with basaltic rocks of Chino Mesa in White Rock Canyon. For the most part it is overlain conformably by unit 1 of these basaltic rocks; but south of Ancho Canyon it interfingers with this unit, and, in places, the lentil is overlain conformably by unit 2 of the basaltic rocks of Chino Mesa. To the west, the lentil interfingers in the subsurface with quartz latite flows of the Tschicoma Formation, as shown by the log of test hole 19.6.17.234 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 Formation. Exposures along Guaje Canyon are apparently typical of the fanglomerate member (fig. 12) although test holes show large amounts of water-washed pumice locally. Exposures of the fanglomerate member in the Los Alamos area extend northwestward from a point just southwest of Otowi bridge along canyons incised in the Pajarito Plateau and northward along the Puye Escarpment. It is exposed in grayish-buff cliffs which have been intricately fluted by erosion. The upper surface of the Puye is

FIGURE 12.—Exposure of the fanglomerate member of the Puye Conglomerate in Guaje Canyon. The white bed that pinches out abruptly is water-washed pumice.

eroded; hence, the original thickness of the fanglomerate member cannot be determined. The thickest known section of the fanglomerate member is 637 feet at test hole 19.6.14.221 in Pueblo Canyon. The member is 209 feet thick at the measured section of the Puye Conglomerate. It thins southward and wedges out just southwest of Otowi bridge, where it abuts against unit 2 of the basaltic rocks of Chino Mesa.

Most of the fanglomerate member apparently is composed of silty sandy conglomerate in which beds of two types commonly can be recognized. These beds differ only by the relative abundance of fine- and coarse-grained material. They intertongue in places. Silt and sand are relatively minor constituents in one type, occurring chiefly in interstices between larger fragments. The amount of silt and sand generally is greater than the amount of gravel and boulders in the other type. Sorting is poor in both types. Near the western margin of the member, where it contains the coarsest material, boulders and angular blocks as large as 5 feet or more in diameter are contained in a matrix whose individual particles range downward in size to silt. In places such boulders are isolated in the finer matrix. Ten miles to the east where the member contains the finest material, beds of silt, sand, and gravel are associated intimately. Bedding is indistinct throughout the member, but layering that dips at least 1° or 2° to the east can be seen at most localities. Locally the dips are more than 10° to the east.

The following section of the fanglomerate member, Santa Fe Group, was measured on the north wall of Guaje Canyon about three-fourths of a mile west of the confluence of Guaje and Los Alamos Canyons. The Puye forms most of the steep slopes and cliffs of the canyon wall here, and the benches and gentle slopes at the top of the canyon are underlain by some old alluvium. The Bandelier Tuff caps the highest part of the north wall of the canyon. The base of the section is in the NW¼NE¼SW¼ sec. 11, T. 19 N., R. 7 E., in a small wash on the south side of a topographic promontory. The altitude of the top of the Puye is about 6,190 feet. The section is shown graphically (section *B*) on plate 1 and was measured by J. E. Weir, Jr., and W. D. Purtymum, April 28, 1960.

	Thickness (feet)
Old alluvium (resting unconformably on the Puye).	
Puye Conglomerate:	
Fanglomerate member:	
12. Conglomerate, pinkish-gray. Contains lenses of gravel ranging in grain size from granules to boulders. Unit contains a 5-ft layer of light-tan conglomeratic siltstone (puddingstone) about 30 ft from base. Boulders 2–3 ft across occur in layers near the top of the unit. Many boulders are composed of porphyritic red and light-green latite	50

	Thickness (feet)
Puye Conglomerate—Continued	
Fanglomerate member—Continued	
11. Siltstone, gray, conglomeratic (puddingstone). Similar to unit 8 below. Unit probably is of laharic origin	17
10. Boulder conglomerate, with silty or Kosic matrix. Boulders are composed of latite and porphyritic quartz latite	4
9. Siltstone, conglomeratic (puddingstone). Unit contains widely dispersed pebbles and a few thin layers of granule gravel. Gravel is composed of volcanic detritus. Unit probably is of laharic origin	56
8. Conglomerate, brownish- to bluish-gray. Gravel ranges in grain size from granules to boulders as much as 3–5 ft across. Matrix is moderately rounded sand and silt and a few lenses of tan siltstone. Gravel is composed of dark-gray and red to purple volcanic ditritus. Porphyritic latite noted	22
7. Siltstone, tan to light- and medium-gray; very pumiceous in lower 8 ft and conglomeratic and pumiceous in upper 5 ft. Gravel bed at top is highly crossbedded. Pumiceous beds contain a small amount of granules composed of latitic volcanic detritus. Pumice and other volcanic debris are rounded and stream worn, or worn in mudflow	13
6. Siltstone, conglomeratic; contains alternate layers and interlenses of volcanic gravel. The gravel ranges in grain size from granules to pebbles and is composed almost exclusively of volcanic detritus. Gravel occurs in crossbedded lenslike layers	36
5. Siltstone, light-tan, medium-bedded; blocky in places. Contains a few gravel lenses composed of volcanic detritus and some arkosic detritus	11
Totavi Lentil:	
4. Gravel, pinkish-gray; very well rounded from stream action. Gravel composed mainly of quartzite, white massive quartz and granite and other felsic rock detritus with some intermixed volcanic detritus. Gravel ranges in size from granules to boulders. Arkosic sand of varied grain size fills interstices in gravel beds. Unit is very friable. Angular unconformity at base of unit	23
Undifferentiated unit (in part):	
3. Sandstone, creamy-gray, silty; contains some lenses that are conglomeratic. Gravel is mostly volcanic detritus	13
2. Conglomerate, bluish- to light-gray, very sandy and friable. Gravel ranges in size from granules to pebbles and a few cobbles. Layer of cream-gray sand, 2 ft thick, is about 5 ft above the base. Gravel is mostly volcanic detritus with some quartzite and arkosic detritus	12
1. Siltstone, pink, sandy, very friable. Bed is exposed extensively in lower Guaje Canyon and is the uppermost pink bed in this vicinity. Apparent dip is 1° in a S. 11° W. direction	10
Base of section.	

Nearly all the detrital fragments are latitic. These fragments are pebbles, cobbles, and boulders and are gray and purplish-gray to red quartz latite and latite. All the fragments are conspicuously porphyritic. Phenocrysts of plagioclase, some of which are more than half an inch long, form about 25 percent of the rocks. Other less common phenocrysts are composed of 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 commonly is partly glassy to glassy.

Light-gray pumice beds ranging in thickness from a thin film to a few feet have been observed on the surface in several places, and such beds are quite thick in places in the fanglomerate member in the subsurface. Test hole 19.6.13.344 in Los Alamos Canyon penetrated 90 feet of water-washed pumice in the lower part of the fanglomerate member, and test hole 14.221 in Pueblo Canyon penetrated 320 feet of similar pumice that lies directly on the Totavi Lentil. These pumice beds are composed of angular to subangular fragments as much as 2 inches in diameter. Locally they contain abundant fragments of porphyritic latite. Ash commonly fills the interstices. The pumice is latitic and tiny phenocrysts of biotite and plagioclase are common. The pumice also contains tiny phenocrysts of hornblende and pyroxene. For the most part these beds seem to be water-lain, but horizontal bedding is well developed in other beds that possibly may have been deposited as ash fall. The fanglomerate member along the Puye Escarpment contains a few thin beds of very fine grained white tuff. These beds, ranging in thickness from about 1–3 feet, rest directly on the Totavi Lentil and are water-laid ash. Abundant diatoms were noted in one specimen collected from this ashy material. Large isolated boulders in a matrix of sandy silt or silty sand occur in places (fig. 13). These beds were deposited as volcanic mudflows or lahars.

The fanglomerate in the subsurface contains flows of basalt. The flows between depths of 176 and 255 feet penetrated by test hole 19.7.20.221 in Pueblo Canyon, and those between depths of 266 and 388 feet penetrated by test hole 19.6.13.344 in Los Alamos Canyon are medium to dark gray. The rock is composed of small phenocrysts of plagioclase and tiny phenocrysts of olivine and clinopyroxene in a fine- to medium-grained groundmass of semifelted plagioclase, clinopyroxene, olivine(?), and magnetite, as determined by study of thin sections. These flows are identical in composition with some of those in unit 2 of the basaltic rocks of Chino Mesa and are correlated with these rocks. The basalt between depths of 410 and 510 feet penetrated by test hole 19.7.20.221 is similar to and also is correlated tentatively with unit 2 of the basaltic rocks of Chino Mesa.

The fanglomerate member rests conformably on the Totavi Lentil and interfingers with parts of the Tschicoma Formation and basaltic

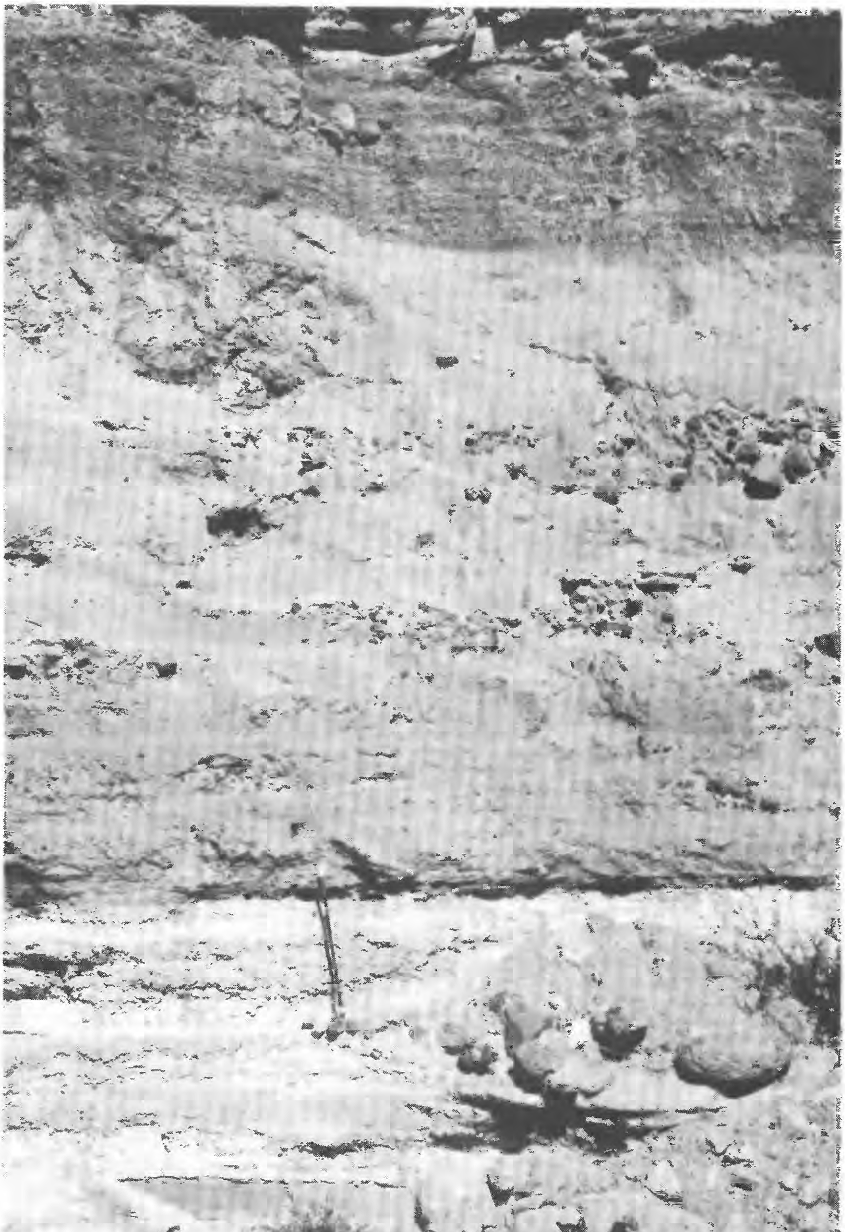

FIGURE 13.—Exposure of the fanglomerate member of the Puye Conglomerate in the upper part of Guaje Canyon near well G5. The white material is water-washed pumice; the overlying material which contains near the top an isolated boulder 2 feet across (in silt-size debris with irregular lenses of conglomerate and breccia), is a lahar about 6 feet thick; the material at the top is water-deposited conglomerate.

rocks of Chino Mesa along its eastern and western margins, respectively, indicating that the fanglomerate is contemporaneous in age with these rocks. C. S. Ross and R. L. Smith (oral communication) also observed that the fanglomerate member interfingers with the easternmost latitic flows of the Tschicoma Formation in Santa Clara Canyon, north of the Los Alamos area. The fanglomerate is overlain in the subsurface by flows of pyroxene andesite of the Tschicoma Formation at test hole 19.6.17.234 in Los Alamos Canyon. The lowest flows of Chino Mesa interfinger with the Totavi Lentil, and the basalt overlying the Totavi Lentil is surely equivalent in age to the lower part of the fanglomerate member. The occurrence within the fanglomerate of basalt that is identical in appearance and mineralogy with some of the flows of unit 2 of the basaltic rocks of Chino Mesa indicates that the basalt of unit 2 was erupted at the time of deposition of the higher parts of the fanglomerate. Rocks that overlie the Puye disconformably include: units 3 and 4 of the basaltic rocks of Chino Mesa, the old alluvium, and the Guaje Member of the Bandelier Tuff.

Age

The age of the Puye conglomerate is believed to be late Pliocene because of its stratigraphic position. However, diatoms found immediately above the Totavi Lentil may be either late Pliocene or early Pleistocene in age.

BASALTIC ROCKS OF CHINO MESA

Definition

The basaltic rocks of Chino Mesa consist of a thick sequence of basaltic to andesitic rocks and minor amounts of included poorly consolidated sediments that form Chino Mesa and adjacent parts of the Cerros del Rio and that cap some outlying mesas and buttes to the north. The sequence is thickest in the interior of the Rio Grande depression, and only its northern and western extensions occur in the Los Alamos area.

Distribution and Thickness

The basaltic rocks of Chino Mesa form the steep walls of White Rock Canyon and cap the high mesas to the east. West of the canyon, these rocks cap a large mesa mainly south of the settlement at White Rock. They are exposed in deep canyons cut in the overlying Bandelier Tuff on the east side of the Pajarito Plateau as far north as Los Alamos Canyon. Most of the basalt was erupted from centers in the Cerros del Rio and flowed northwestward into the Los Alamos area, where the older units interfinger with the Puye Conglomerate and an old alluvium unit. The basaltic sequence is more than 1,300 feet thick in the vicinity of Chino Mesa.

Units

In order to determine the relation of the basaltic rocks of Chino Mesa to the Puye Conglomerate, five units of these rocks were mapped in the area. Unit 1, the oldest unit, consists of basalt flows, basaltic tuff, and interbedded, poorly consolidated sediments that are exposed above the undifferentiated unit of the Santa Fe Group in the lower wall of White Rock Canyon. Unit 1 is as much as 360 feet thick in the southern part of the Los Alamos area and thins gradually northward. Individual basalt flows generally are not more than 25 feet thick, and columnar jointing generally is well developed. The basalt flows range from dark gray to almost black and commonly have a faint green hue. All are porphyritic. Small phenocrysts of olivine, the largest of which are almost a quarter of an inch in diameter, are contained in all specimens, although they are greatly altered in many places. The phenocrysts in some specimens are altered to a mixture of saponite and celadonite (R. L. Smith, oral communication, 1952) and to iddingsite in others. Several specimens contain small xenocrysts of quartz surrounded by a rim of radiating crystals of augite. The groundmass is composed of sodic labradorite, clinopyroxene that probably is pigeonite, some olivine that commonly is altered similarly to the phenocrysts, and some magnetite. The basaltic tuffs of the unit are distinctive and are very common in the southern part of the exposure belt. 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 rocks and some that have been derived from the Tschicoma Formation. Some poorly consolidated sediments are interbedded near the north end of the unit. At the mouth of Mortandad Canyon, the interbedded sedimentary rocks consist of arkosic sandstone and conglomerate.

Unit 2, conformably overlying unit 1, forms the main cliffs along White Rock Canyon, caps much of Chino Mesa east of the canyon, and west of the canyon unit 2 caps a mesa south of White Rock. Unit 2 is more than 850 feet thick on Chino Mesa and thins gradually northward and wedges out. It consists mainly of flows of basalt and basaltic andesite and a few local beds of basaltic tuff and thin sandstone. The flows generally are more massive than those of unit 1, and, in places, individual flows are more than 50 feet thick. They range from gray to dark gray and generally are lighter in color than those of the underlying unit. Some specimens contain small phenocrysts of olivine only. Some contain phenocrysts of olivine and pyroxene; others contain olivine, pyroxene, and plagioclase; and still others, small phenocrysts of pyroxene only. The groundmass is composed of plagioclase, clinopyroxene, and a small amount of magnetite. The groundmass of some specimens may contain a small amount of olivine.

The plagioclase ranges in composition from sodic labradorite to calcic andesine.

Unit 3 forms the dissected hills east of Chino Mesa and southeast of Sagebrush Flats and is exposed west of the Rio Grande in Los Alamos Canyon and in Sandia and Mortandad Canyons northeast of White Rock. The unit is more than 500 feet thick east of Chino Mesa and about 120 feet thick in Los Alamos Canyon. This unit consists of massive steep-sided flows of dark-gray basalt that commonly have a thick zone of breccia at their base and edges. 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 and a small amount of olivine and magnetite.

Unit 4 consists of two flows of basalt that were erupted on the east side of Sagebrush Flats and flowed northwestward into the Los Alamos area. This unit caps the mesa at Sagebrush Flats and also La Mesita. West of the Rio Grande, the flows of unit 4 are exposed east of White Rock, cap the mesa south of Totavi, and are exposed on a small butte north of Otowi bridge. Unit 4 is about 240 feet thick on the west side of Sagebrush Flats and thins northward. The upper of the two flows terminates just east of Totavi. The lower one continues westward for a short distance and then abuts against a massive flow of unit 3. Both flows of unit 4 are identical in lithology. 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 observed. The groundmass is composed of very sodic labrodorite, clinopyroxene, olivine, and magnetite, in order of abundance.

Unit 5 consists of cinder cones and local basalt flows on Sagebrush Flats and in Chaquehui Canyon north of Bandelier National Monument headquarters, and there is a small dome of this basalt on the west side of La Mesita. The rocks of unit 5 are almost black where they are not oxidized, but they are brownish red in the cinder cones where they are highly vesicular and oxidized. They are inconspicuously porphyritic, and phenocrysts cannot be seen in some hand specimens. Tiny phenocrysts of olivine and a few of pyroxene and labrodorite are apparent in thin sections. The fine-grained to glassy groundmass is composed chiefly of pyroxene and a small amount of olivine, magnetite, and plagioclase microlites.

Contacts With Adjacent Rocks

Unit 1 of the basaltic rocks of Chino Mesa rests unconformably on the main body of the undifferentiated unit of the Santa Fe Group in White Rock Canyon south of Ancho Canyon. Farther north in

White Rock Canyon, unit 1 interfingers with the Totavi Lentil of the Puye Conglomerate, and still farther north flows of the unit rest conformably on the Totavi Lentil. Unit 1 wedges out on the east side of the canyon into or beneath the upper tongue of the undifferentiated unit, which rests on the Totavi Lentil in this area. Unit 1 on the west side of White Rock Canyon opposite La Mesita wedges out northward between the Totavi Lentil and the overlying flows of unit 2.

Unit 2, conformably overlying unit 1, interfingers with the upper tongue of the undifferentiated unit and wedges out northward beneath flows of unit 4 on the east side of White Rock Canyon at Sagebrush Flats. On the west side of the canyon, unit 2 persists farther to the north, overlaps unit 1 to rest on the Totavi Lentil and finally abuts the fanglomerate member of the Puye Conglomerate opposite the north end of La Mesita. Basalt in the fanglomerate member observed in the drill cuttings from wells 19.6.13.344 and 19.7.20.221 is similar petrographically to the basalt of unit 2; thus. the fanglomerate member and unit 2 probably interfinger.

Unit 3 rests disconformably on unit 2 at Chino Mesa. West of the Rio Grande in canyons between White Rock and Totavi, unit 3 rests locally on unit 2, on the fanglomerate member of the Puye Conglomerate, and on an old alluvium unit. Unit 3 interfingers with the old alluvium unit near the top of the hill west of Totavi. Thus, unit 3 is at least partly equivalent to the old alluvium and is disconformable on the Puye Conglomerate.

Flows of unit 4 rest with erosional unconformity on the main body of the undifferentiated unit of the Santa Fe Group and on a remnant of the Totavi Lentil on La Mesita. Unit 4 at Sagebrush Flats rests on the upper tongue of the undifferentiated unit of the Santa Fe Group and abuts flows of unit 3 and unit 2 that are topographically higher than unit 4. Unit 4 west of the Rio Grande near White Rock lies on unit 2. To the north near Totavi, unit 4 rests unconformably on the Puye Conglomerate and abuts unit 3. Units 4 and 3 in the area near Totavi and White Rock are overlain with erosional unconformity by the Bandelier Tuff.

The cinder cones and local flows of unit 5 are the most recent of the basaltic rocks of Chino Mesa and overlie with unconformity all the older rocks with which they are in contact. The unconformable relation to unit 4 can best be seen near the eastern and western edges of Sagebrush Flats. A local cone and flow of unit 5 are overlain and surrounded by the Bandelier Tuff in Chaquehui Canyon north and east of Bandelier National Monument headquarters.

Age

The oldest units of the basaltic rocks of Chino Mesa probably are late Pliocene and the youngest are Pleistocene. Units 1 and 2 interfinger with the Puye Conglomerate, of probable late Pliocene age, and with the upper body of the undifferentiated unit of the Santa Fe Group, which may be of Pliocene or Pleistocene age. Units 3 and 4 are of post-Puye age and early or middle Pleistocene. Flows and cinder cones of unit 5 are of middle or late Pleistocene age. Immediately east of the Los Alamos area small basaltic flows correlated with those of unit 5 are associated with a low pediment or terrace along the Rio Grande.

OLD ALLUVIUM

Definition

Remnants of high-level alluvial deposits crop out in a few places in the east-central part of the Los Alamos area. These deposits, here called the old alluvium unit, were observed by V. C. Kelley (written communication) and were called informally the Culebra Lake clay and gravel by Kelley.

Distribution and Thickness

The old alluvium is best preserved west of Totavi on the ridge north of Los Alamos Canyon. It also is preserved north of Totavi on the ridge north of Guaje Canyon, and a patch is preserved on the ridge north of Contrayerba Canyon. In addition local outcrops occur to the south in Mortandad Canyon northeast of White Rock and at the northern tip of Sagebrush Flats. The old alluvium ranges in thickness from 0 to more than 100 feet.

Lithology

The unit is well exposed in four sets of beds along State Highway 4 near the top of the hill west of Totavi. The lowest bed is basaltic tuff 1 foot thick. This bed is overlain by brownish-gray thinly laminated clay about 20 feet thick which weathers to a dull brown. Next is a bed of buff to brownish-yellow silty sand and gravel about 50 feet thick. This is overlain by a bed of gray thinly laminated clay about 25 feet thick that weathers to a dirty grayish green. Only the sand and gravel and the overlying green clay have been observed to the north beyond Guaje Canyon. The old alluvium unit may have been deposited in a lake formed by damming of the Rio Grande by basalt flows of unit 3, as suggested by V. C. Kelley (written communication).

Contacts With Adjacent Rocks

The alluvium was deposited on a pediment surface cut on the Puye Conglomerate, but at places it abuts against the edge of a higher partly dissected pediment also cut on the Puye. The allumium at the exposure along State Highway 4 west of Totavi is in contact with a steep-sided flow of basalt of unit 3, which has a tongue that pinches out within the alluvium.

Age

The patches of old alluvium west of the Rio Grande rest unconformably on a Pleistocene pediment and are overlain unconformably by the Bandelier Tuff. The patch at the north end of Sagebrush Flats is overlain unconformably by flows of unit 4 of the basaltic rocks of Chino Mesa. Thus, on the basis of stratigraphic position, the age of the old alluvium unit is Pleistocene.

VOLCANIC ROCKS OF THE JEMEZ MOUNTAINS VOLCANIC PILE

With the exception of the caldera fill, the rocks are of volcanic origin in the Sierra de los Valles, the Valles Caldera, and the Jemez and Pajarito Plateaus of the Jemez Mountains volcanic pile. The formations of volcanic origin in this area include the Tschicoma formation, Bandelier Tuff, Cerro Toledo Rhyolite, Cerro Rubio Quartz Latite, and Valles Rhyolite.

TSCHICOMA FORMATION

DEFINITION

The Tschicoma (pronounced Chee-koma) Formation includes the older rocks of the complex interior mass of the complex interior of the Jemez Mountains volcanic pile. Smith (1938, p. 937) first mapped these rocks as the Chicoma volcanic formation in the Abiquiu quadrangle north of the Los Alamos area. According to Smith (1938, p. 939), the name was first used by E. S. Larsen in an unpublished manuscript. No type locality was specified, but it is presumed that the formation was named for the high peak composed of these rocks about 5 miles north of the Los Alamos area that is now designated Tschicoma Mountain on the Geological Survey topographic map of the Polvadera Peak quadrangle (1953). The recent spelling of "Tschicoma" is used in this report.

The Tschicoma Formation in the Los Alamos area consists of two mappable units. The older unit is composed of latite and quartz latite flows, and the younger unit is composed of pyroxene andesite flows.

DISTRIBUTION AND THICKNESS

Rocks of the Tschicoma Formation in the Los Alamos area form most of the rugged slopes in the upper drainage of Guaje and Los Alamos Canyons. The unit also forms most of the segment of the Sierra de los Valles which bounds the southern part of the Valles Caldera. The Tschicoma Formation has been penetrated in test holes on the Pajarito Plateau and is exposed in a small inlier in Pueblo Canyon north of Los Alamos. It is believed to underlie the Bandelier Tuff in a band a few miles wide on the western side of the plateau.

The base of the Tschicoma Formation is not exposed in the area, and part of the formation has been removed by erosion; thus, its total thickness is unknown. The exposed part of the Tschicoma Formation in Pajarito Canyon adjacent to Pajarito Mountain at the east side of the Valles Caldera is more than 2,600 feet thick. The formation thins rapidly eastward beneath the Bandelier Tuff on the Pajarito Plateau and interfingers with the upper part of the undifferentiated unit and the Puye Conglomerate of the Santa Fe Group.

LATITE AND QUARTZ LATITE UNIT

The latite and quartz latite unit forms nearly all the exposed rocks of the Tschicoma Formation and occurs in flows that range in thickness from about 200 to 400 feet. The rocks are mainly gray to purplish gray, but in places they grade to reddish brown. Both the latite and the quartz latite contain abundant phenocrysts of plagioclase that tend to be slightly larger and more abundant in the quartz latites where they reach more than half an inch in their greatest dimension and commonly constitute more than 25 percent of the volume of the rock.

In general the quartz latite flows crop out north of Los Alamos Canyon and the Quemazon Canyon fork of this canyon, where they form distinctive hummocky slopes. Jointing is pronounced, and in places the flows grade to blocky breccia. The upper parts of the flows grade upward from crystalline rock to pumiceous glass in some exposures. The abundant plagioclase phenocrysts are in large part actually xenocrysts and obviously were not in equilibrium with the groundmass in which they occur. Some of these xenocrysts have a "motheaten" appearance that is caused by tiny areas of included glass indicating partial melting. Some also are embayed by groundmass material, and some are resorbed to the extent that only ghostlike remnants are recognizable. The autochthonous plagioclase phenocrysts are fresh in appearance and exhibit good albite twinning. The other phenocrysts consist of quartz, biotite, hornblende, and augite. The quartz is subrounded and embayed. The biotite and hornblende are in various stages of resorption. The groundmass of these rocks is composed of plagioclase, alkalic feldspar, augite, a small amount of fine magnetite, and various amounts of glass.

The latite flows are exposed south of Los Alamos Canyon, and they appear to have lapped against the quartz latite flows near the axis of this canyon. Test hole 20.5.34.233 at the head of Quemazon

Canyon penetrated latite from depths of 627 to 890 feet and quartz latite from depths of 890 to 1,269 feet, the total depth of the hole. The latite forms somewhat smoother slopes than the quartz latite, and the latite flows appear to have been more regular and less pasty than the quartz latite flows. The flows are similar, however, and presumably belong to the same period of eruptions. The latite contains large phenocrysts and xenocrysts of plagioclase that generally are identical in composition with those of the quartz latite. The small mafic phenocrysts are augite, biotite, and hornblende with the biotite and hornblende showing varying amounts of resorption. Augite is more abundant in the latite than in the quartz latite. The latite does not contain quartz phenocrysts or xenocrysts. The groundmass of the latite consists of plagioclase, some alkalic feldspar, augite, some fine magnetite, and, in places, some glass similar to that of the quartz latite. The groundmass of the latite, however, contains less alkalic feldspar than does the groundmass of the quartz latite.

PYROXENE ANDESITE UNIT

The pyroxene andesite unit is exposed only in a small area north of Quemazon Canyon east of Valle de los Posos, where it lies disconformably on a flow of quartz latite. The unit in the subsurface at hole 19.6.17.234 about 4½ miles to the southeast consists of two or three flows having an aggregate thickness of 347 feet. The rocks of this unit are finely porphyritic and range from gray to dark gray. Locally they contain a few scattered phenocrysts of plagioclase as much as a quarter of an inch in diameter, but for the most part the phenocrysts can be observed only by close examination. The phenocrysts consist of zoned plagioclase and pyroxene, the pyroxene including both augite and hypersthene. One specimen contains xenocrysts of brown biotite. The groundmass is composed of felted plagioclase, pyroxene, and some magnetite.

CONTACTS

The base of the Tschicoma Formation is not exposed in the Los Alamos area; thus, the relations of these rocks to older rocks can only be inferred. Basalt interbedded in the undifferentiated unit of the Santa Fe Group was penetrated by wells in Guaje Canyon (fig. 9), and the basalt below an altitude of 5,400 feet in the three westernmost wells in that canyon apparently is the oldest rock of the Jemez Mountains volcanic pile. If so, the lowest part of the Tschicoma Formation must interfinger with the uppermost part of the undifferentiated unit. At these same wells, the upper part of the undifferentiated unit, above the highest basalt flow (at an altitude of about

5,700 ft), contains debris from the quartz latite flows of the Tschicoma. This debris is particularly abundant in the westernmost wells. This indicates that deposition of the very uppermost part of the undifferentiated unit was concurrent with eruption of some of the older quartz latite; and therefore the older quartz latite flows surely interfinger with the undifferentiated unit in the subsurface of the westernmost part of the Pajarito Plateau.

Beds of the Totavi Lentil of the Puye Conglomerate at hole 19.6.17.234 in Los Alamos Canyon are interbedded with the upper part of the quartz latite sequence of the Tschicoma. The fanglomerate member of the Puye contains debris from both the quartz latite and latite flows, and is overlain in the subsurface near hole 17.234 by flows of the pyroxene andesite unit of the Tschicoma Formation.

The Tschicoma Formation on the Pajarito Plateau is overlain with erosional unconformity by the Bandelier Tuff. The Tschicoma Formation at the base of Rabbit Mountain in the Sierra de los Valles near the southwest corner of the Los Alamos area is cut by a rhyolite dome which belongs to the Cerro Toledo Rhyolite of Quaternary Age. Tschicoma rocks farther north along the eastern edge of the Valles Caldera are masked on the lower slopes of the Sierra by alluvial fan deposits of Quaternary age which were derived largely from the Tschicoma Formation.

AGE

The relation of the Tschicoma Formation to the upper part of the undifferentiated unit of the Santa Fe Group and to the Puye Conglomerate indicates that the Tschicoma Formation is of Pliocene and possibly early Pleistocene age instead of Miocene age, as was assumed by early workers (Darton, 1928 and Bryan, 1938). It was assumed by earlier workers that the Tschicoma Formation was correlative with the main body of volcanic rocks in the San Juan region of Colorado. The youngest part of the undifferentiated unit of the Santa Fe Group, however, is apparently middle or upper Pliocene in age (Frick, 1937), and debris from the Tschicoma Formation does not extend greatly below this part of the undifferentiated unit in Guaje Canyon. The pyroxene andesite unit overlying the Puye Conglomerate probably includes some of the youngest flows of the Tschicoma Formation. These youngest flows may be of early Pleistocene age.

TEWA GROUP

The name Tewa (pronounced tay-wah) Group is given to the rhyolite tuff and the rhyolite and quartz latite domes that constitute the latest eruptive rocks of the Jemez Mountains volcanic pile. The area has no distinctive physiographic feature from which to take a name for the diverse group; therefore, the name Tewa (after the Indian tribe of the area and by whose name the surrounding mountains were once known) was chosen. The Tewa Group in the Los Alamos area includes the Bandelier Tuff, Cerro Toledo Rhyolite, Cerro Rubio Quartz Latite, and Valles Rhyolite.

BANDELIER TUFF

Definition

The term "Bandelier Rhyolite Tuff" was used for a map unit in the Abiquiu quadrangle north of the Los Alamos area by Smith (1938, fig. 4, p. 937). Smith did not define or describe the unit but only listed it (1938, p. 959) as one of the Quaternary formations in the Abiquiu quadrangle. The name of the formation obviously was taken from the exposures of rhyolite tuff in the area of Bandelier National Monument many miles south of the Abiquiu area, although this was not specified by Smith. The unit mapped by Smith as the Bandelier Rhyolite Tuff extends southward into the Los Alamos area and is the thick unit of rhyolite tuff that forms the cap of much of the Pajarito Plateau. The name is shortened to Bandelier Tuff in this report.

The Bandelier Tuff is divisible into three mappable units. The lowest part of the formation is composed mainly of unconsolidated pebble-size pumice, here named the Guaje Member. A massive aggregate of poorly sorted pumiceous rhyolite tuff breccia, here named the Otowi Member, overlies the Guaje Member. The upper unit is a cliff-forming welded rhyolite tuff, here named the Tshirege Member.

Smith did not specify a type section for the Bandelier Tuff. The Guaje Member is uniform or mainly uniform throughout its extent; the Otowi Member may show considerable variation around the volcanic pile; and the Tshirege Member is highly variable owing to different degrees of welding. In this report a type section will be designated only for the Guaje Member. Type areas will be designated for the Otowi and Tshirege Members. (See p. 47, 48, 54.)

Distribution and Thickness

The Bandelier Tuff in the Los Alamos area forms the cap of most of the Pajarito Plateau from the Sierra de los Valles eastward to White Rock Canyon. In the northeastern part of the area where deep canyons have been incised into the plateau, the Bandelier caps long fingerlike ridges some of which extend for several miles in an east-west direction between the canyons. A small remnant of the Bandelier Tuff is exposed on the east wall of White Rock Canyon southwest of Sagebrush Flats. The tuff is exposed also in the Valles Caldera at the western edge of the area mapped, on the rim of the caldera east of Valle de los Posos, and on the north flank of the Sierra de los Valles northeast of the caldera. The tuff forms spectacular cliffs, which are nearly vertical in places, along the east-west and southeast-northwest trending canyons of the plateau.

The Bandelier Tuff is thickest near the western margin of the Pajarito Plateau. The total thickness of the Bandelier penetrated in hole 19.6.17.234 and exposed nearby in Los Alamos Canyon is about 1,050 feet. West of there the Bandelier Tuff thins rapidly as it laps onto the Tschicoma Formation of the Sierra de los Valles. The Bandelier also thins to the east and is only 260 feet thick on the east side of the Pajarito Plateau in the area between Totavi and White Rock. Although many deep canyons have been cut in the Bandelier the gently sloping mesas between canyons are, in many places, coincident with the original upper surface of the unit; thus, the thickness given probably is nearly equal to the original thickness of the formation.

Guaje Member

The Guaje (pronounced Wah-hee) Member of the Bandelier Tuff is named for exposures in and near Guaje Canyon, and the member is well exposed in the workings of the White Eagle pumice mine on the ridge north of Guaje Canyon and near the top of the high hill on the south side of Guaje Canyon southwest of the pumice mine. A typical section was measured on the north side of this hill in the SE¼NW¼SE¼ sec. 4, T. 19 N., R. 7 E. and is given below. The Guaje Member is composed of unconsolidated white rhyolitic lump pumice or lapilli tuff. The pumice fragments contain tiny phenocrysts of sanidine and quartz. The fragments range in size from dust to lumps 2 inches in diameter. The finest particles and material showing the best ash-fall bedding are in the upper 5–10 feet of the member. The lower part of the member commonly is massive. The type section is shown graphically (section *C*) on plate 1 and was measured by J. E. Weir, Jr., as follows.

Top of section.

	Thickness (feet)
Bandelier Tuff:	
Guaje Member:	
4. Lump pumice, light-gray to nearly white; composed mostly of pumice fragments some of which are as much as 2 in. across. Unit is very friable. A few fragments of dark rock and the largest pumice fragments are subrounded. Very distinct ash-fall bedding from bottom to top	5.6
3. Lump pumice, light-gray to nearly white; weathers to pale buff. Composed mainly of pumice fragments ranging in size from ash up to lapilli, and some fragments are as much as 3 in. across. Larger fragments of pumice appear fibrous because the pore space exists as tiny elongate tubes. Some granule-size xenoliths of rhyolite and latite. May be a single ash-fall bed. Disconformity at base	19

Santa Fe Group:
  Puye Conglomerate (upper part):
    Fanglomerate member:

	Thickness (feet)
2. Siltstone, pinkish-tan, slightly conglomeratic. Top of unit is eroded at point of measurement, and the unit is 4 ft thick about 15 ft northeast of measured section	0.5
1. Conglomerate, dark-gray; consists of boulders and cobbles grading downward into a granule conglomerate about 6 ft thick, that grades downward into a basal boulder conglomerate. Apparently persistent boulder and cobble bed is typical of Puye and is composed of latitic and other volcanic debris from the Jemez Mountains volcanic pile	10

Base of section.

The Guaje Member is exposed almost continuously along the Puye Escarpment and in the deep canyons in the northeastern part of the area. The member is 57 feet thick at hole 19.6.17.234 in Los Alamos Canyon, and 25 feet thick in Guaje Canyon at the type locality. It is absent on the slopes of the Sierra de los Valles, and it thins toward the east and wedges out between the underlying basaltic rock of Chino Mesa and the overlying Otowi Member of the Bandelier Tuff in the area between White Rock and Totavi. The member is absent to the south in White Rock Canyon but has been noted in the subsurface in Ancho Canyon.

The Guaje Member rests unconformably on all older rocks with which it is in contact. In the northeastern part of the area, the member overlies the Puye Conglomerate or local patches of the old alluvium unit. The Guaje Member overlies the pyroxene andesite unit of the Tschicoma Formation in the subsurface at hole 19.6.17.234. In the area between Totavi and White Rock it overlies units 2, 3, and 4 of the basaltic rocks (fig. 14) of Chino Mesa and a local patch of the old alluvium unit. The Guaje Member is overlain conformably by the Otowi Member of the Bandelier Tuff.

Otowi Member

The Otowi (pronounced O-toe-wee) Member of the Bandelier Tuff is named for exposures in the vicinity of the Otowi ruins (NE¼NE¼ sec. 18, T. 19 N., R. 7 E.) in Pueblo Canyon. The type locality of the Otowi Member is the Otowi section of the Bandelier National Monument. A specific type section cannot be chosen although all parts of the unit have certain common characteristics. Throughout the Los Alamos area it is chiefly a single pumice flow. The Otowi Member forms a slope between a thin ledge of the underlying Guaje Member and the overlying Tschirege which forms the steep cliffs in the upper part of the canyon walls. The cone-shaped erosional remnants (called tent rocks) of the Otowi, as shown in figure 15, are common in the member elsewhere. The member in the Los Alamos area ranges

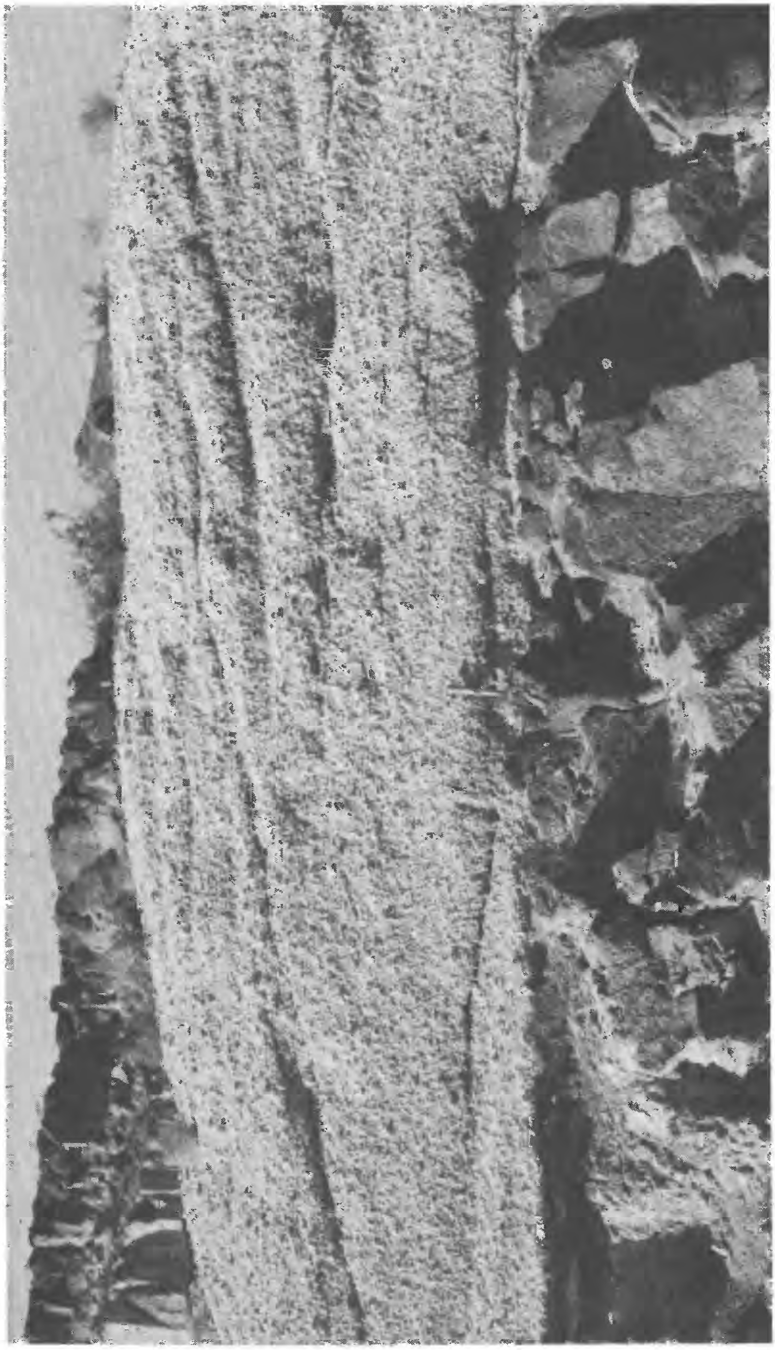

FIGURE 14.—Lump pumice of the lowermost ash-fall bed of the Guaje Member of the Bandelier Tuff lying disconformably on basalt at the top of the hill west of Totavi.

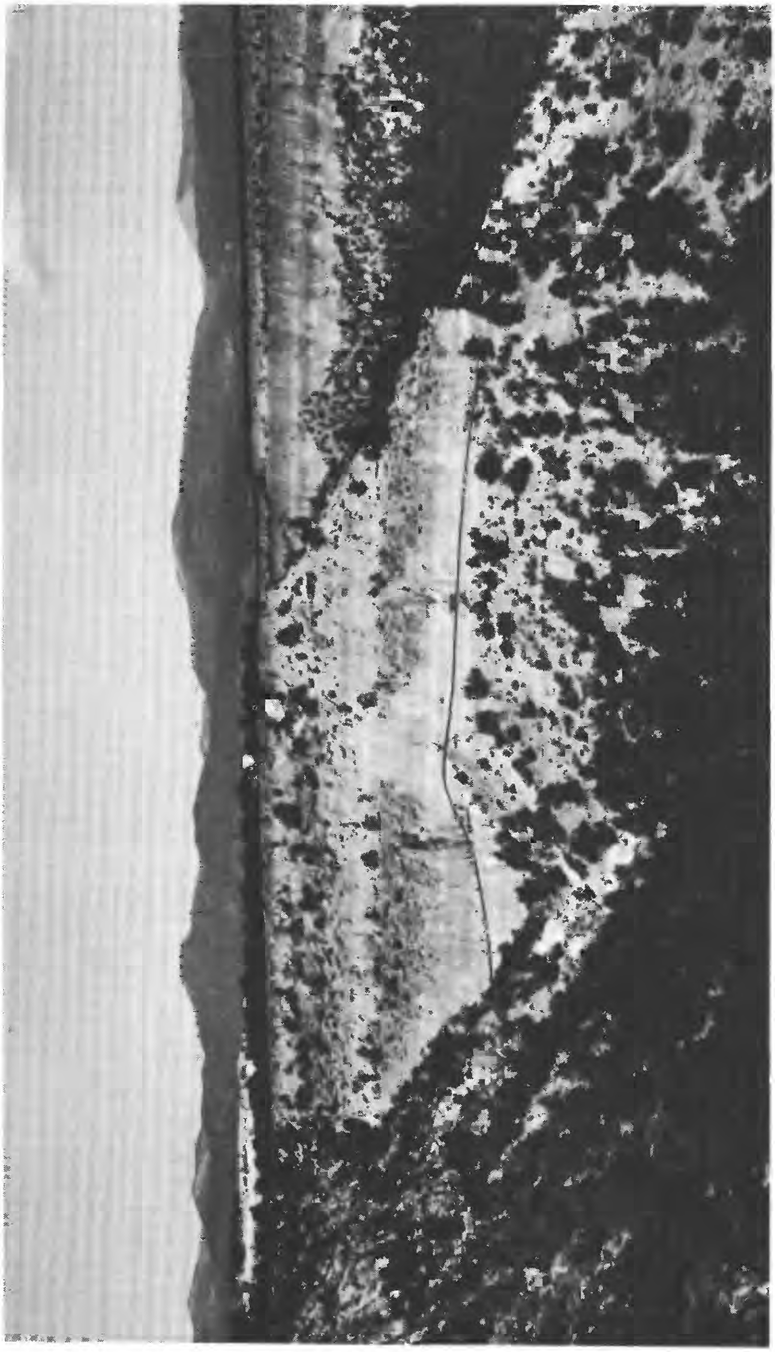

FIGURE 15.—Upper part of the Guaje Member (lower right), the Otowi Member with conical erosional remnants, and the Tshirege Member (in cliff) of the Bandelier Tuff, Pueblo Canyon a short distance east of Otowi Ruins.

in thickness from 0 to at least 215 feet. The 215-foot-thick section is in test hole 19.6.17.234.

The following section of the Bandelier Tuff was measured on the slopes of the south side of the mesa north of Los Alamos Canyon, a short distance west of the confluence of the arroyos in Los Alamos and Pueblo Canyons and is fairly typical of the member in the Los Alamos area. The base of the section is in the NW¼NE¼NW¼ sec. 21, and the top of the section is in the SE¼SE¼SW¼ sec. 16, T. 19 N., R. 7 E. The altitude of the top of the Otowi Member at this place is about 6,500 feet. The section is shown graphically (section D) on plate 1 and was measured by J. E. Weir, Jr., May 18, 1960.

	Thickness (feet)
Top of section.	
Tshirege Member (lower part):	
8. Tuff, light-gray, pumiceous; weathers to salmon-pink, mainly small lumps of pumice. Lithologically similar to the Otowi Member except that there may be some incipient welding and the unit contains less ash-size material and little or no rock debris; forms cliffs above ash-fall material below	30+
7. Pumice, light-gray, ash-fall	1.4
6. Pumice, light-gray; weathers to pink at top. Contains blebs of carbonaceous material similar in color to those in unit 4 below	4.0
5. Pumice, light-gray, ash to lapilli. Contains discontinuous irregular dark-greenish-gray streaks. Ash-fall bedding obvious	.8
Otowi Member:	
4. Siltstone, pink. Contains granules and cobbles, with one gray vesicular rhyolite boulder observed. Highly pumiceous and similar lithologically to tuff below. Locally, at the base, is a caliche layer less than 1 in. thick. Contact with unit 3 is gradational	1.0
3. Tuff, light-buff; weathers pinkish-brown. Highly pumiceous, containing long-tube pumice fragments as much as 5 in. across. Weathers into conical shapes (tent rocks). Spires or cones typically have cobble-size holes on their weathered surfaces as the result of pumice fragments having weathered out. Tuff contains some granule- to cobble-size fragments of rhyolite and latite. Larger fragments occur near middle of the unit. Upper 20 ft of tuff tends to weather to columnar shapes and weathers to lighter colors than the rocks below; in the upper 20 ft of the unit there are fewer rock fragments than in the rocks below	138.0
Guaje Member:	
2. Tuff, ash-fall; composed mainly of lump pumice with a few latite granules. Distinct ash-fall bedding from bottom to top and conformable with overlying Otowi Member. Particles are angular to subangular, ranging in size from medium-grained sand to granules and pebbles. Rocks dip 10° N., in a 40° W. direction	5.0
1. Pumice, light-gray; mostly lumps that are fibrous in appearance due to pore space present as tiny slender tubes. Lumps are as much as 2 in. across in a matrix of ash. A few fragments of latite are disseminated through the unit. Unite is very poorly exposed except in the bottom of a small stream cut in the canyon wall. Basalt crops out in the streambed below base of the section and upstream about 50 yds	12.0
Base of section.	

The Otowi Member is a buff-colored massive aggregate of poorly sorted rhyolitic pumice fragments and some fine pumiceous glass, all of which weathers to a chalky light gray. Fragments range in size from silt to pumice lumps that are 5 inches or so in diameter and that are composed of pale-buff unaltered glass. In a few thin sections a trace of montmorillonite is present on the walls of tubes in pumice. The fragments contain phenocrysts of sanidine and quartz and a few tiny grains of magnetite. Many fragments contain a trace of biotite and hornblende. Some fragments of rocks derived from the Tschicoma Formation are included. These fragments mainly are latitic rocks, but some are light-gray rhyolite. The fragments of Tschicoma rocks are not evenly distributed, and, where most abundant, they generally constitute less than 5 percent of the rock. The aggregate is slightly consolidated but mostly poorly indurated. In the Los Alamos area it consists of a single thick pumice flow with a few beds of ash-fall pumice present in places at the top of the unit, as just east of the main gate to the Los Alamos town site (fig. 16), but at most places these ash-fall beds have been eroded away during the interval of erosion between the the Otowi and Tshirege Members. In addition, in places, as in the upper part of Pueblo Canyon, there is at the top of the unit some water-washed pumice containing boulders of latitic rock derived from the Tschicoma Formation.

The Otowi Member is widely distributed on the Pajarito Plateau and crops out in the canyons of the central and eastern parts of the plateau. North of Guaje Canyon the member caps most of the central part of the plateau. On the west side of the Pajarito Plateau the Otowi Member pinches out onto the Tschicoma Formation in the Sierra de los Valles and is overlapped by the Tshirege Member of the Bandelier Tuff, which persists farther to the west. The member is thickest near Los Alamos and is thinnest in the southeastern part of the area where it pinches out over some of the topographically highest areas of basalt.

The Otowi Member rests conformably on the Guaje Member where the Guaje is present. Elsewhere the Otowi Member rests on a pre-Bandelier erosion surface of considerable relief which was cut on the Puye Conglomerate, the old alluvium unit and the basaltic rocks of Chino Mesa. The Otowi Member is overlain with erosional unconformity by the Tshirege Member. The interval of time between deposition of the Otowi Member and the Tshirege Member is believed to have been relatively short but canyons as deep as 150 feet were cut in places in the Otowi Member during the interval.

FIGURE 16.—Otowi and Tshirege Members of the Bandelier Tuff showing the disconformity between the two members, south side of Pueblo Canyon just east of Los Alamos. A small amount of ash-fall pumice at the top of the Otowi Member is beneath the disconformity near the prow of the point but is cut out by the disconformity near the center of the photograph.

Tshirege Member

The Tshirege (pronounced Ser-a-gay) Member of the Bandelier Tuff is named for exposures in the vicinity of Tshirege ruins (NW¼ sec. 5, T. 18 N., R. 7 E.) where this member forms the capping rock over a large area of the Pajarito Plateau. Because of variations in welding and devitrification in the member from place to place, a specific type section is not designated herein. Instead, a type area, the Pajarito Plateau and the adjacent lower slopes of the Sierra de los Valles, is designated as having virtually continuous exposures showing the range of lithologic variations.

The Tshirege Member is a welded rhyolite tuff composed of small fragments of crystallized pumice and crystals and crystal fragments of sanidine and quartz in a welded tuff matrix. Dark minerals are scarce although traces of crystal fragments of biotite, hornblende, and pyroxene have been observed. As seen in thin sections, the matrix generally is composed of crystallized shards and a little fine-grained magnetite. The tuff is mostly ash-flow debris, but it contains also a few thin beds of ash-fall pumice at the base and at the top. Neither of these sets of ash-fall beds is thick enough to map. Over most of the Pajarito Plateau, the Tshirege is commonly porous and friable and ranges from buff to pale gray. Near the western margin of the plateau and on the flanks of the Sierra de los Valles, the tuff is more intensely welded, is commonly nonporous, and is gray to purplish gray. In places on the slopes of the Sierra de los Valles it is very intensely welded and consists of dark-colored glass with stringers of collapsed lumps of devitrified pumice.

The following section was measured on the south face of the mesa north of Los Alamos Canyon east of the confluence of the arroyos in Los Alamos and Pueblo Canyons. The Tshirege Member caps the mesa and has been eroded to form the steep cliffs of the upper part of the mesa. The base of the section is in the NW¼NW¼NE¼ sec 21, T. 19 N., R. 7 E. The top of the section is near the highest point of the mesa at an altitude of about 6,680 feet in the SW¼SE¼SW¼ sec. 16, T. 19 N., R. 7 E. The section is shown graphically (section E) on plate 1 and was measured by J. E. Weir, Jr., and W. D. Purtymun, May 18, 1960. The section is typical of the Bandelier only near the outer edge of the Pajarito Plateau in this particular vicinity.

	Thickness (feet)
Top of section.	
Tshirege Member:	
7. Tuff, light- to creamy-gray; contains sanidine and quartz phenocrysts and greenish-brown devitrified pumice fragments. Abundant sanidine and quartz phenocrysts in upper part of member. Contains a few rock fragments ranging in size from granules to pebbles. Unit forms gently sloping top of mesa	49

Tshirege Member—Continued	*Thickness (feet)*
6. Tuff, light-purplish-gray. Sanidine and quartz phenocrysts are larger and more abundant than in the rocks in interval 4. Some rock fragments are included. Light-gray layered moderately crossbedded material at base of unit. Tuff has concave and convex jointing which is slightly columnar. Unit forms cliff	31
5. Tuff, purplish-gray; weathers buff. Contains a few phenocrysts of sanidine and quartz and pinkish-purple devitrified pumice inclusions in a highly devitrified fine-grained groundmass. Frothy friable bed at top of unit contains quartz and sanidine crystals in a gray pumiceous groundmass. Unit forms a slope	47
4. Tuff, light-pinkish-gray. Contains pink to buff devitrified pumice fragments as much as ½ in. across. Surface is pockmarked by holes where crystallized pumice fragments have weathered out. Matrix is fine-grained devitrified ash with very few small rock fragments included. Unit forms cliff that displays more or less massive prismatic columnar jointing	26
3. Tuff, salmon- to brick-pink, highly pumiceous. Composed of pumice, ash, lapilli, and larger fragments as much as 3 in. across. Contains a few rock fragments which increase in amount and size (up to granules) toward top of unit. Upper part of the unit tends to weather in spalls making a convex cliff. Uppermost beds form a bench and a notch in the cliff	46
2. Tuff, light-gray, pumiceous; contains lapilli-size pumice in an ash matrix. Unit is lithologically somewhat similar to the underlying Otowi Member, except that the unit contains almost no rock fragments. Unit weathers "dirty" pinkish brown like the Otowi Member and has spirelike weathered forms. There may may be some incipient welding of unit	16
1. Pumice, light-gray ash-fall, and some salmon-pink siltstone(?). May include some Otowi ash-fall material, but if so the disconformity separating these falls is not obvious	8.1
Base of section.	

The Tshirege Member stands in very steep to vertical cliffs that generally are weathered to tan or orange brown. Fairly regular jointing is common, and, locally, columnar jointing is conspicuous. Nearly horizontal planes in the cliffs seem to mark the boundaries between successive ash flows in places, but some of the horizontal planes in the unit are due to unknown phenomena.

The Tshirege Member caps the higher parts of the Pajarito Plateau as long fingerlike mesas between the deep canyons, and the member extends from White Rock Canyon to the middle and upper slopes of the Sierra de los Valles. North of Guaje Canyon the Tshirege Member is preserved on the northeast flank of the Sierra de los Valles and on the western part of the Pajarito Plateau. Small outliers cap mesas as far east as the Puye Escarpment. The member crops out also in the central part of the Valles Caldera near the western edge of the area. The member ranges in thickness from 100 to 200 feet near the eastern margin of the area to about a thousand feet (estimated) at the head of the Rito de los Frijoles in the southwestern part of the area.

The Tshirege Member rests with erosional unconformity on all older rocks with which it is in contact. The Tshirege Member on the Pajarito Plateau rests on the Otowi Member and fills eroded channels in that member. The Tshirege Member overlaps the Otowi Member to the west and rests on the Tschicoma Formation in the Sierra de los Valles. Also, in the Sierra de los Valles, the Tshirege Member laps onto some of the Cerro Toledo Rhyolite domes.

Age

Physiographic evidence indicates that the Bandelier Tuff is of Pleistocene age. Deep canyons cut in the Tschicoma Formation (of Pliocene and possibly early Pleistocene age) were filled by the Bandelier Tuff in the central and western parts of the area, and the Tshirege Member of the tuff fills a deep canyon cut in basalt (also of Pliocene(?) and Pleistocene age) west of White Rock Canyon in the southeastern part of the area. This canyon and the remnant of the Tshirege-filled canyon east of White Rock Canyon are believed to have been occupied by a tributary to the Rio Grande and by the Rio Grande prior to the Bandelier eruptions. The base of the Bandelier fill in the channel east of White Rock Canyon is only 200 feet above the present level of the Rio Grande. Also, although the Bandelier Tuff is soft and has been entrenched deeply, the original upper surface of the formation has been preserved over much of the Pajarito Plateau. This physiographic evidence leads the author to believe that the Bandelier is probably at least as young as middle Pleistocene. If one believes that the Ortiz surface of Bryan is approximately middle Pleistocene, then he is forced to believe that the Bandelier is very young, as the tuffaceous eruptions certainly are post-Ortiz as shown by the fact that they are postbasalt (TQb_4), and this basalt can be traced to the surface of the Ortiz pediment.

CERRO TOLEDO RHYOLITE

Definition and Distribution

The rocks that form a group of extrusive volcanic domes in parts of the Sierra de los Valles just northeast and southeast of the Valles Caldera are here named the Cerro Toledo Rhyolite. The name was taken from Cerro Toledo, a peak in the Sierra de los Valles northeast of the Valles Caldera.

The Cerro Toledo Rhyolite crops out at the designated type locality on the northeast side of the Valles Caldera in a steep forested northwestward-trending ridge—the Sierra de Toledo—between Rito de los Indios and Valle de los Posos. This ridge is formed by numerous coalescing domes. The highest parts of this ridge are more than 10,000 feet in altitude. Rabbit Mountain on the southeast side of the caldera, which rises to an altitude of 9,938 feet, is a composite dome of Cerro Toledo Rhyolite.

Lithology and Contacts With Adjacent Rocks

The Cerro Toledo Rhyolite is a fine-grained light-gray banded rock. In thin section the rock is seen to be composed of tiny phenocrysts of sanidine, quartz, and traces of partly resorbed hornblende and biotite, all in a fine-grained groundmass that is commonly microspherulitic and is composed of sanidine and silica.

Domes of Cerro Toledo Rhyolite cut across and lap onto rocks of the Tschicoma Formation near Rito de los Indios at the northwest end of Sierra de Toledo and at Rabbit Mountain. In turn, the Cerro Toledo Rhyolite is cut and overlapped by the Cerro Rubio Quartz Latite dome at Cerro Rubio, and by the Valles Rhyolite domes on the south side of Sierra de Toledo. The Cerro Rhyolite is overlain with erosional unconformity by the Tshirege Member of the Bandelier Tuff on the northeast side of Sierra de Toledo and by Quaternary fan deposits on the edge of the Valles Caldera.

Age

Inasmuch as the Cerro Toledo Rhyolite domes cut and lap onto the Tschicoma Formation, they are Pleistocene in age. These domes are older than the Tshirege Member of the Bandelier Tuff, as on Turkey Ridge, and the basal few feet of the Tshirege contains numerous fragments derived from the underlying Cerro Toledo Rhyolite. It is believed that the Cerro Toledo domes were extruded after the cycle of eruptions which produced the Guaje and Otowi Members of the Bandelier. They probably were extruded within and at the margin of an elliptical-shaped caldera having a north-south axis and which extended from north of the Sierra de Toledo southward to Rabbit Mountain with the later being a rim dome on this early caldera.

CERRO RUBIO QUARTZ LATITE

Definition

The name Cerro Rubio Quartz Latite is here given to the rocks on two conical extrusive volcanic domes that form Cerro Rubio and an unnamed peak on the northeast side of the Valles Caldera north of Valle de los Posos. The name was suggested by C. S. Ross and R. L. Smith (written communication). These two domes, which are here designated the type section, are the only occurrence of the Cerro Rubio Quartz Latite in the Los Alamos area.

Lithology and Contacts With Adjacent Rocks

The Cerro Rubio Quartz Latite is a light- to dark-gray rock which, at the southerly of the two domes, weathers grayish red. The rock is composed of tiny phenocrysts of plagioclase, hypersthene, and partly resorbed hornblende and biotite in a fine-grained groundmass of plagioclase, sanidine, and quartz. The rock in places is somewhat glassy.

The Cerro Rubio Quartz Latite is intruded into the Cerro Toledo Rhyolite on the west side of Cerro Rubio. The Tshirege Member of the Bandelier Tuff on the east side of the dome lies unconformably against the quartz latite.

Age

The Cerro Rubio Quartz Latite is younger than the Cerro Toledo Rhyolite; thus it is Pleistocene in age. It is older than the Tshirege Member of the Bandelier Tuff.

VALLES RHYOLITE

Definition

The name Valles Rhyolite is here given to the rhyolite domes in the Valles Caldera in the west-central part of the Los Alamos area. These domes, here designated the type locality, are forested heavily and stand above the intervening grass-covered valleys as masses ranging in size from small hills to large mountains. The smaller domes are nearly circular or elliptical in plan and are more or less conical. The larger mountains are composite masses of several domes and are irregular in plan, but their upper surfaces are fairly domal.

Large composite domes of Valles Rhyolite in the eastern part of the Valles Caldera include Cerro del Medio, Cerros del Abrigo, and, on the western edge of the area, Cerros de Trasquilar. The Cerros de los Posos are smaller domes at the northeast edge of the caldera. Cerro la Jara and other small unnamed domes occur in the southern part of the caldera near the western edge of the area. Other domes of Valles Rhyolite are in the Valles Caldera west of the area treated in this report.

Lithology and Contacts With Adjacent Rocks

The domes of Valles Rhyolite exhibit zoning more or less parallel to the outer surface. Where the domes have been only slightly eroded, the outer rind is a jumble of blocky pumice and pumiceous glass that grades from white to light gray to pale pink. Toward the interior of this zone are local areas of obsidian. The glassy rind changes farther inward to slightly porous light-gray rhyolite that is slightly glassy and commonly spherulitic, and in places there is interstitial obsidian between the spherulites. The rocks in deeply eroded parts of the domes are light-gray fine-grained rhyolite. Abundant phenocrysts of sanidine and quartz were observed in thin sections of all types of these rocks. Tiny phenocrysts of hornblende and biotite and traces of plagioclase were observed in some specimens. The groundmass of the nonglassy rocks is composed of sanidine and silica.

The bases of the domes are covered by younger alluvium and fan material; thus, their relation to older rocks is only partly known. The northernmost dome of Valles Rhyolite in the Cerros de Trasquilar cuts the Tschicoma Formation. The Valles Rhyolite of the western dome of the Cerros de los Posos cuts the Cerro Toledo Rhyolite. The Valles Rhyolite is not in contact with the Cerro Rubio Quartz Latite or the Bandelier Tuff at any place in the east half of the Valles Caldera. West of the Los Alamos area, however, the Valles Rhyolite was extruded through the Tshirege Member of the Bandelier Tuff. In view of these relations, it is established that the Valles Rhyolite is younger than the Cerro Rubio Quartz Latite which is pre-Tshirege in age.

Age

The Valles Rhyolite is of Pleistocene Age and is the youngest igneous rock in the Los Alamos area. The domes were extruded in the Valles Caldera after the cycle of tuffaceous eruptions which formed the Tshirege Member of the Bandelier Tuff and before the caldera was party filled by alluvium and fan material.

CALDERA FILL

DEFINITION

A lake occupied the steep-walled depression after formation of the Valles Caldera. Sediments accumulated in this lake and partly filled the caldera. The lacustrine deposits are poorly exposed and are known mainly from test drilling in the Valles Caldera during the summer of 1949. (See table 1.) The lacustrine deposits consist of clayey silt, silty clay, sand, and gravel, and may include some pyroclastic debris. (See figs. 17–19.)

722-218 O—64——5

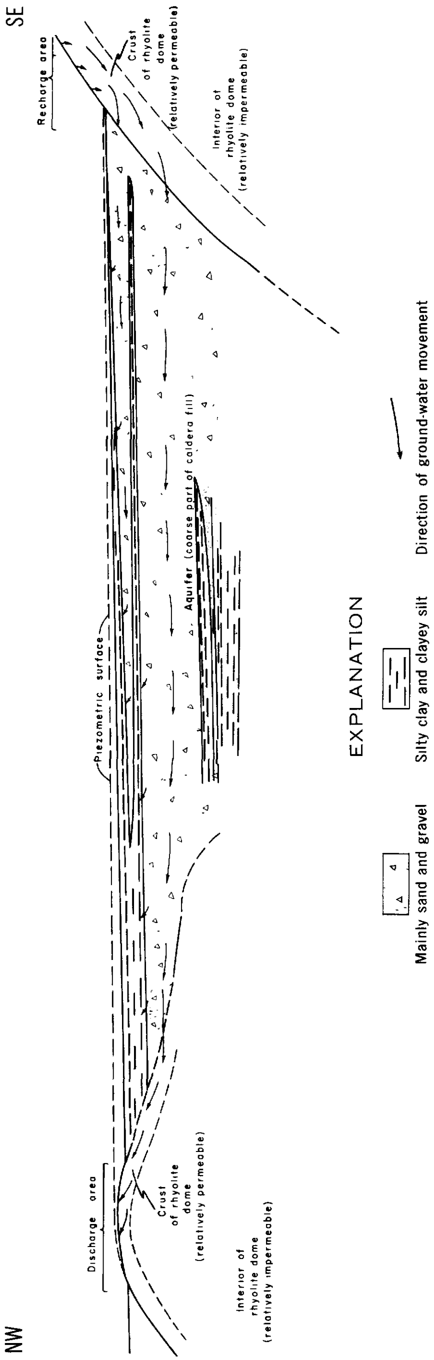

FIGURE 17.—Generalized schematic diagram along the axis of San Antonio Creek in Valle Toledo, showing movement of ground water.

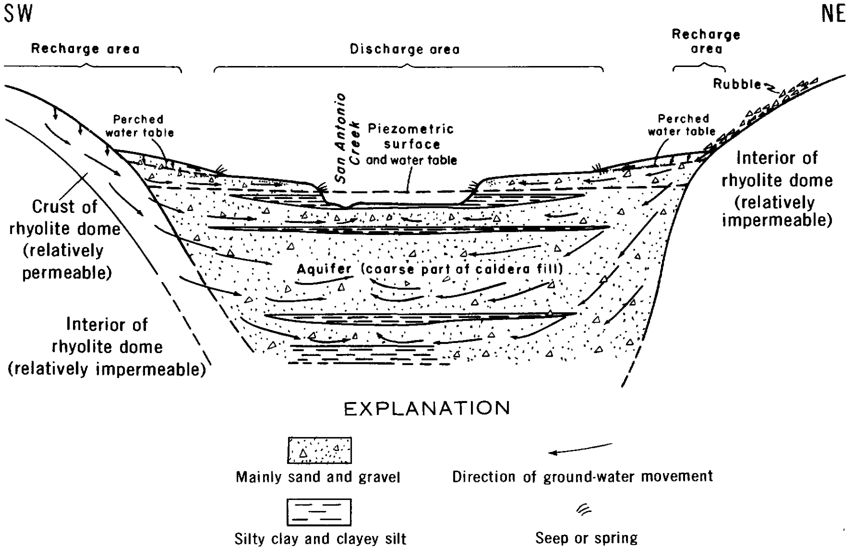

FIGURE 18.—Generalized schematic diagram across the axis of San Antonio Creek in Valle Toledo, showing movement of ground water.

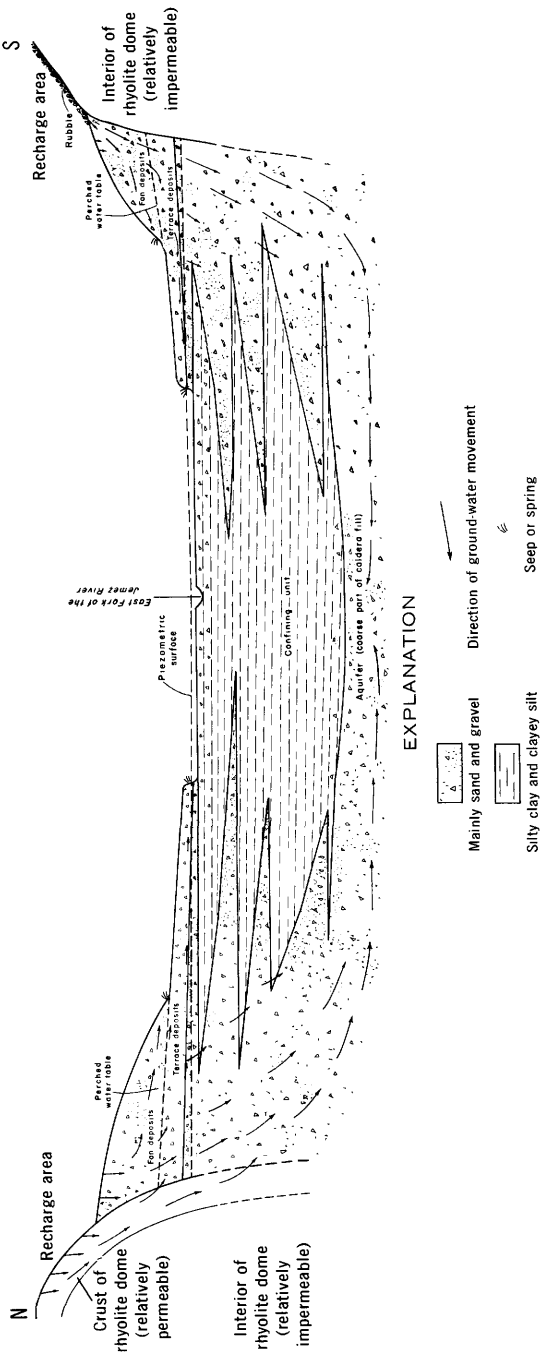

FIGURE 19.—Generalized schematic diagram of Valle Grande showing movement of ground water.

TABLE 1.—*Selected logs of wells and test holes in the Los Alamos area, New Mexico*

Valles Caldera area

[Well 19.5.19.134. Land surface altitude 8,506 ft]

	Thickness (feet)	*Depth (feet)*
Quaternary alluvium:		
Sand and gravel, silty to clayey, gray. Sand composed of quartz and sanidine. Gravel composed of pumice, rhyolite, and obsidian. Black silt and clay, particulary in upper few feet	10	10
Caldera fill:		
Clay, silty, to clayey silt and some dark-olive-green sand and gravel. Sand and gravel consist of fragments of rhyolite, pumice, obsidian, quartz, and sanidine	45	55
Clay, silty, to clayey silt; olive-green, diatomaceous and containing some sand and gravel composed of rhyolitic debris between 100 and 135 ft	235	290
Sand and gravel, silty, gray. Sand and gravel composed mainly of pumice and pumiceous glass	10	300
Gravel, sandy, light-gray. Fine- to medium-grained gravel composed of white to light-gray pumice and pumiceous glass, quartz, and sanidine. Water bearing	85	385
Gravel, sandy, light-gray. Fine-grained gravel composed of rhyolite and pumice that vary in relative proportion in various beds; although, in general, pumice increases with depth. Sand consists of pumiceous glass, quartz, sanidine, rhyolite, and obsidian. Some beds silty. Water bearing	475±	860±
Same as from 385–860 ft, but latitic material begins to appear both in fine-grained gravel and sand and increases with depth	325±	1,185

[Well 20.4.24.214. Land surface altitude 8,650 ft]

	Thickness (feet)	*Depth (feet)*
Quaternary alluvium:		
Gravel, sandy, and some light-gray clay. Fine- to course-grained gravel composed of light-gray rhyolite, pumiceous glass, pumice, and obsidian. Medium to coarse sand composed of quartz and sanidine. Black silty clay present in upper 3 ft	12	12
Caldera fill:		
Gravel, sandy to silty, light-gray. Fine- to medium-grained gravel is composed of light-colored rhyolite, pumice, and pumiceous glass. Fine- to course-grained sand is quartz and sanidine. Silt composed of glassy debris	48	60
Clay, silty to sandy, diatomaceous, gray to olive	20	80
Gravel, sandy to silty, light-gray. Gravel composed chiefly of pumiceous glass, sand of quartz and sanidine, and silt of glassy debris	15	95

TABLE 1.—*Selected logs of wells and test holes in the Los Alamos area, New Mexico*—Continued

Valles Caldera area

[Well 20.4.24.214. Land surface altitude 8,650 ft]—Continued

	Thickness (feet)	*Depth (feet)*
Caldera fill—Continued		
Gravel, sandy, and some pink to buff silt. Fine- to medium-grained gravel composed chiefly of pink to buff pumice. Sand mainly quartz and sanidine. Silt, composed of glassy material, present in small amount through much of the unit, and there are three well-developed silt beds between depths 115–120, 125–130, and 135–140 ft. Water bearing	45	140
Gravel, sandy, silty, and clayey, light-gray. Fine- to medium-grained gravel composed mainly of pumice and rhyolite and a few pieces of latite. Sand mainly quartz and sanidine	35	175
Gravel, sandy, light-gray. Fine- to medium-grained gravel composed mainly of light-gray pumice and some pieces of rhyolite and latite. Sand mainly quartz and sanidine. Some clayey silt between 310 and 325 ft. Water bearing	170	345
Gravel, sandy, silty, and clayey, light-gray. Fine- to medium-grained gravel composed mainly of white to light-gray pumice and pumiceous glass and some pieces of latite. Sand composed of quartz and sanidine	25	370
Gravel, sandy, light-gray. As from 345 to 370 ft but without silt. Water bearing	40	410
Silt, clayey and sandy, yellow to olive-buff to maroon	5	415
Gravel, sandy, silty and clayey, light-gray to gray. Fine- to medium-grained gravel composed mainly of rhyolite, pumice, and pumiceous glass. Sand mainly quartz and sanidine	7	422
Silt, clayey, to silty clay, olive-brown to buff to maroon	23	445
Cerro Toledo Rhyolite:		
Rhyolite, light-gray	207	652

Valles Caldera area

[Test hole 20.5.34.411. Land surface altitude 9,505 ft]

	Thickness (feet)	*Depth (feet)*
Bandelier Tuff, Tshirege Member:		
Tuff, welded, lavender-gray	295	295
Bandelier Tuff, undifferentiated:		
Tuff, pumiceous, light-gray to buff-colored	332	627
Tschicoma Formation, latite, and quartz latite unit:		
Latite, gray to grayish-red; contains conspicuous phenocrysts of plagioclase as much as ½ in. long and tiny phenocrysts of pyroxene, biotite and hornblende	263±	890±
Quartz latite, pale- to pale-pinkish-gray; contains conspicuous phenocrysts of plagioclase as much as ½ in. long and small to tiny phenocrysts of quartz, biotite, hornblende, and pyroxene	379±	1,269 T.D.

TABLE 1.—*Selected logs of wells and test holes in the Los Alamos area, New Mexico*—Continued

Rio Grande area

[Test hole 19.6.17.234. Land surface altitude 7,178 ft]

	Thickness (feet)	*Depth (feet)*
Quaternary alluvium:		
Gravel and sand, gray. Gravel fine- to coarse-grained and composed of pieces of latite porphyry and welded tuff. Sand coarse and composed of crystals and crystal fragments of quartz and sanidine. A zone of perched water occurs between 14 and 27 ft	27	27
Bandelier Tuff, Tshirege Member:		
Tuff, lavender-gray, nonporous, densely welded	35	62
Tuff, as above, but somewhat less welded and finely porous	62	124
Tuff. Zone contains much red to orange-buff clayey to silty debris; and abundant fragments of obsidian, glassy rhyolite, and latite	6	130
Tuff, light-buff, highly pumiceous; contains some fragments of latite	70	200
Bandelier Tuff, Otowi Member:		
Tuff, highly pumiceous, pale-buff	215	415
Bandelier Tuff, Guaje Member:		
Pumice, white; in lumps as much as 2 in. in diameter. Perched water occurs between 450 and 472 ft	57	472
Tschicoma Formation, pyroxene andesite unit:		
Andesite, dark-gray; contains a few tiny phenocrysts of plagioclase as much as ⅛ in. long and pyroxene as much as 1/16 in. long, in a glassy groundmass, much of which is finely vesicular	69	541
Andesite, dark-gray to gray; contains phenocrysts from 472 to 541 ft, in a fine-grained groundmass of plagioclase and pyroxene	159	700
Andesite, grayish-purple; otherwise identical with overlying and underlying rock. Zone probably "top" of the underlying flow	15	715
Andesite, gray; contains a few tiny phenocrysts of plagiochase and pyroxene as much as 1/16 in. long in a fine-grained groundmass of plagioclase and pyroxene	98	813
Andesite, reddish-brown, finely vesicular; otherwise identical in appearance to material from 715–813 ft; the zone represents the basal part of the overlying zone	6	819
Puye Conglomerate:		
Conglomerate, gray to brown. Zone composed of angular to subangular gravel and boulders and some sand and silt. Gravel and boulders composed of porphyritic latite and quartz latite and sand and silt composed of fine latitic debris	391	1,210
Tschicoma Formation, latite, and quartz latite unit:		
Quartz latite, light-gray to gray; contains conspicuous phenocrysts of plagioclase as much as ¼ in. across and less conspicuous phenocrysts of pyroxene in a glassy groundmass that grades to pumiceous glass	50	1,260

TABLE 1.—*Selected logs of wells and test holes in the Los Alamos area, New Mexico*—Continued

Rio Grande area

[Test hole 19.6.17.234. Land surface altitude 7,178 ft]—Continued

	Thickness (feet)	*Depth (feet)*
Tschicoma Formation, latite, and quartz latite unit—Continued		
Quartz latite, gray to lavender-gray; contains conspicuous phenocrysts of plagioclase as much as ¼ in. across and less conspicuous phenocrysts of pyroxene, hornblende, biotite, and quartz	220	1,480
Totavi Lentil of Puye Conglomerate:		
Conglomerate, gray; composed mainly of pebbles of quartzite	10	1,490
Tschicoma Formation, latite and quartz latite unit:		
Quartz latite, lavender- to purplish-gray; contains conspicuous phenocrysts of plagioclase and rather inconspicuous phenocrysts of quartz, hornblende, biotite, and pyroxene	190	1,680
Quartz latite, purplish-gray to grayish-purple to brown; contains phenocrysts as from 1,490–1,680 ft. Zone may be largely breccia from 1,680 to 1,790 ft, and it is all breccia from 1,790 to 1,840 ft	160	1,840
Tuff breccia, light- to very pale-lavendar-gray, latitic. Zone composed of colorless to white pumiceous glass and angular fragments of light- to light-lavender-gray semiglassy latite that carries conspicuous phenocrysts of plagioclase, some inconspicuous phenocrysts of quartz, and a few tiny phenocrysts of biotite and hornblende	160	2,000

[Well 19.7.4.411 (G2). Land surface altitude 6,056 ft]

	Thickness (feet)	*Depth (feet)*
Quaternary alluvium:		
Boulders, cobbles, gravel, and sand. Sand composed of quartz, feldspar, and latitic debris. Coarser particles of porphyritic latite and quartz latite	13	13
Puye Conglomerate:		
Conglomerate, sandy to silty, gray. Gravel and cobbles composed of porphyritic latite and quartz latite. Sand of quartz, feldspar, and latitic debris. Silt of glassy to partly glassy material	17	30
Totavi Lentil:		
Conglomerate, sandy, gray. Gravel composed of materials derived from Precambrian sources. Arkosic sand	45	75
Undifferentiated unit, Santa Fe Group:		
Sandstone, fine- to coarse-grained, conglomeratic, silty, pinkish-gray. Arkosic sand. Gravel composed of porphyritic latite	50	125
Conglomerate, sandy to silty, pinkish-gray. Gravel composed of latite, quartzite, pegmatitic material, and granite. Arkosic sand	70	195
Sandstone, fine- to coarse-grained, silty, grayish-pink. Sand mainly arkosic and containing some latitic debris	45	240
Sandstone, fine- to coarse-grained, conglomeratic, pinkish-gray. Arkosic sand. Porphyritic quartz latite and pumice gravel. Water bearing	93	333

TABLE 1.—*Selected logs of wells and test holes in the Los Alamos area, New Mexico*—Continued

Rio Grande area

[Well 19.7.4.411 (G2). Land surface altitude 6,056 ft]—Continued

Undifferentiated unit, Santa Fe Group—Continued	*Thickness (feet)*	*Depth (feet)*
Conglomerate, sandy and silty, pinkish-gray. Fine-grained gravel composed of porphyritic quartz latite and pumice. Arkosic sand. Silt composed of glassy debris	60	393
Conglomerate, sandy, pinkish-gray. Fine-grained gravel composed of porphyritic quartz latite and pumice. Arkosic sand. Water bearing	183	576
Conglomerate, sandy to slightly silty, pinkish-gray. Nearly identical with unit from 333 to 393 ft but less silt. Water bearing	104	680
Conglomerate, sandy, silty, and clayey, grayish-pink. Fine gravel of latitic debris. Arkosic sand	39	719
Conglomerate, sandy, pinkish-gray. Fine-grained gravel composed of latitic debris. Arkosic sand. Water bearing	47	766
Conglomerate, sandy, silty, and clayey, pinkish-gray. Fine-grained gravel composed of volcanic debris. Arkosic sand	64	830
Sandstone, fine- to coarse-grained, slightly silty. Arkosic sand. Water bearing	120	950
Siltstone, clayey and silty clay, grayish-pink	20	970
Sandstone, fine- to medium-grained, silty, grayish-pink. Arkosic sand. Water bearing	30	1,000
Siltstone, clayey and clay, silty, grayish-pink	36	1,036
Sandstone, fine- to coarse-grained, silty, grayish-pink. Arkosic sand. Water bearing	134	1,170
Siltstone, sandy, grayish-pink	35	1,205
Sandstone, fine- to medium-grained, very silty, grayish-pink. Arkosic sand. Unit is in part water bearing	80	1,285
Clay, grayish-pink	10	1,295
Sandstone, fine- to medium-grained and sandy siltstone, interbedded; some thin clay beds. Arkosic sand. Unit is water bearing from 1,305 to 1,315 and 1,350 to 1,360 ft	180	1,475
Sandstone, fine- to medium-grained, grayish-pink. Sand composed of arkose. Water bearing	55	1,530
Sandstone, fine- to medium-grained and sandy siltstone, interbedded, grayish-pink; some thin beds of clay. Arkosic sand. Parts of the unit are water bearing, as follows: 1,550–1,560, 1,595–1,605, 1,645–1,655, 1,680–1,690 ft	160	1,690
Siltstone, grayish-pink; some thin beds of clay	50	1,740
Sandstone, fine- to medium-grained, silty, grayish-pink. Arkosic sand. Water bearing	20	1,760
Clay, grayish-pink	20	1,780
Siltstone, grayish-pink	40	1,820
Sandstone, fine- to medium-grained, silty, grayish-pink. Arkosic sand. Water bearing	10	1,830
Sandstone, fine- to medium-grained and sandy siltstone, interbedded, grayish-pink; some thin beds of clay. Arkosic sand	176	2,006

DISTRIBUTION AND THICKNESS

The lacustrine deposits are covered at most places by younger alluvial fans and terrace material but they crop out at a few places in the caldera. Beds of clayey silt crop out in the Valle Toledo along the edges of terraces north and south of San Antonio Creek and on both sides of the Rito de los Indios. The beds of clayey silt crop out also in two small areas in Valle Grande below the terrace on the north side of the East Fork of Jemez River about half a mile southwest of hole 19.5.19.133. These outcrops are too small to indicate on the geologic map (pl. 1). The lacustrine beds underlie the terrace and fan deposits in much of Valle Toledo, Valle Grande, and Valle de los Posos, as indicated by test drilling. The total thickness of the lacustrine deposits is not known, but hole 19.5.19.134 in Valle Grande was drilled 1,175 feet into the caldera fill without penetrating older rocks; however, the deepest material drilled in this hole was probably pyroclastic debris.

LITHOLOGY

The lacustrine beds are best exposed in Valle Toledo several hundred feet south of hole 20.4.14.443 where a bed of clayey silt about 10 feet thick is exposed in the lower part of the slope beneath the terrace on the south side of the valley. The silt is olive green and weathers to olive buff or light gray. Some of the silt is diatomaceous. The bedding ranges from massive to thinly laminated. The silt is clayey to sandy in another exposure and contains pebbles of pumiceous glass and rhyolite as much as 1 inch in diameter. The clayey silt in the exposures in Valle Grande contains pebbles of rhyolite.

Drill cuttings from 15 holes, which range in depth from 285 to 1,185 feet (table 2), indicate that the lacustrine deposits are composed predominantly of gravel (probably including some pyroclastic debris) and smaller amounts of silty clay and clayey silt. The gravel, with various amounts of sand and silt, is composed mainly of pebbles of white to light-gray pumice and pumiceous glass which invariably contains tiny phenocrysts of sanidine and quartz. Some pieces contain tiny phenocrysts of biotite. Other pebbles are composed of rhyolite, glass, and porphyritic latite. The rhyolite varies in type but the most common variety is light gray, very finely porous, and microspherulitic. Most particles contain tiny phenocrysts of sanidine and quartz. Some contain tiny phenocrysts of hornblende. The pebbles of glass are composed of gray to black obsidian. Pebbles of porphyritic latite, which are relatively uncommon, are purplish gray and contain phenocrysts of plagioclase.

The largest whole pebbles that were washed from the test holes by artesian water discharging at the land surface were about 2 inches in diameter. However, the particles probably increase in size to large boulders toward the margins of the rhyolite domes and near the edge of the caldera. The sand mixed in the gravel is composed of crystals and crystal fragments of sanidine and quartz and particles of pumiceous glass. Silt in some beds of gravel is composed of fine rhyolitic material.

The gravel contains beds of clayey silt and silty clay. The clayey beds range from olive brown through olive green to olive buff and are composed of fine rhyolitic material and various amounts of clay. Some of the clay beds contain appreciable amounts of gravel and many contain abundant diatom tests. Several specimens examined microscopically by C. S. Ross and R. L. Smith (oral communication) contain very fine rhyolitic material and montmorillonite-type clay.

The beds of clayey silt and silty clay in the Valle Toledo are interbedded in and interfinger with a main body of gravel (figs. 17–18). As indicated by exposures and test-hole data, a lens of clayey beds almost 100 feet thick in the vicinity of hole 20.4.14.443 thins and interfingers with gravel to the east. Clayey beds of deeper levels in hole 20.4.24.214 disappear eastward. The few data do not define the extent of clayey material toward the north and south sides of the valley, but the log of hole 20.4.13.144 and ground-water data indicate that some beds extend for considerable distances to the north but pinch out in the gravel before reaching the caldera wall.

A thick body of clayey silt and silty clay in the Valle Grande (fig. 19) overlies a main body of gravel that probably includes some pyroclastic debris. The logs of holes 19.4.13.341, 26.222, 19.5.17.223, 19.133, 19.134, 19.134a, and 19.424 indicate that the thick body of clayey material is thickest 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 gravel, as indicated by water-worn pieces of pumice and rhyolite recovered from the seven holes, but some material, particularly that from the deeper part of hole 19.5.19.134 which extended to 1,185 feet, may be pyroclastic debris.

It was not determined whether pumice and rhyolite fragments taken from holes 19.5.4.111 and 20.5.33.312 on the east side of the caldera were gravel or pyroclastic debris. The writer believes that the upper part of the caldera fill in this area is gravel and that the gravel grades downward into pyroclastic material.

The sediments composing the lacustrine deposits were derived mainly from the pumiceous crusts of the rhyolite domes in the Valles Caldera. The pumice gravel and much of the clayey silt and silty clay are products of these crusts. The partly glassy to crystalline fine-grained rhyolite came from more deeply eroded parts of these domes. Latitic pebbles probably were derived from the Tschicoma Formation on the caldera rim.

TABLE 2.—*Records of wells and test holes in the Los Alamos area, New Mexico*

Location: See text for description of location numbering system.
Altitude of land surface: Altitude read from topographic maps reported to nearest foot; altitude obtained by spirit leveling reported to nearest tenth of a foot.
Specific capacity: From a pumping test after completion of the well; expressed as gallons per minute per foot of drawdown.
Use of water: N, not used; Ws, nuclear waste study; Ps, public supply; S, stock.
Remarks: L, log of well included in report; Ca, chemical analysis of water included in report.

Location	Locale	Date completed	Altitude of land surface above mean sea level (feet)	Depth of well (feet)	Principal water-bearing unit	Water level at completion of well (22.9) above (−7.5) below land surface (feet)	Specific capacity (gpm per foot)	Use of water	Remarks
Valles caldera area									
19.4.13.341	Valle Grande	Nov. 1949	8,533.9	630	Caldera fill	−16.9		N	
26.222	do	do	8,490.6	589	do	22.9		N	Ca
19.5.4.111	Divide between Valle Grande and Valle de los Posos.	Oct. 1949	8,990	420	do			N	
17.223	Valle Grande	do	8,595	600	do			N	
19.133	do	Nov. 1949	8,506.4	595	do	11.4		N	Ca
19.134	do	do	8,506.6	1,185	do	9.6	10	N	Ca, L
19.134a	do	do	8,506	595	do	10.8		N	Ca
19.424	do	do	8,549.4	634	do	−15.4		N	
20.4.13.144	Valle Toledo	Oct. 1949	8,769	530	do	−71.4		N	
14.443	do	do	8,603	285	do	−7.5		N	Ca
24.213	do	do	8,647	405	do	38.5		N	Ca
24.213a	do	do	8,648	410	do	35.4		N	
24.214	do	July 1949	8,650	652	do	36.0	50	N	Ca, L
20.5.19.333	do	do	8,720	444	do	19.5		N	Ca
33.312	Valle de los Posos	do	8,930	800	do			N	
34.233	East rim of caldera	1949	9,505	1,269	Tschicoma Formation			N	L

Rio Grande area

18.6.13.444	Ancho Canyon	Apr. 1950	6,224	55		Dry		N	
19.6.9.443	Rim of Pueblo Canyon	Mar. 1950	7,243.1	1,205	Tschicoma Formation	−1,166.0	0.6	Ws	
13.344	Los Alamos Canyon	Nov. 1949	6,625.3	815	Puye Conglomerate	−749.9	.5	Ws	
14.221	Pueblo Canyon	do	2,646.4	789	do	−760.1	1	Ws	
14.221a	do	do	6,646	133	do	−121		Ws	
17.234	Los Alamos Canyon	Sept. 1949	7,178	2,000	Tschicoma Formation	−970(±5)			L
36.141	Pajarito Canyon	Mar. 1950	6,705	300		Dry			
19.7.4.133(G3)	Guaje Canyon	July 1951	6.139.4	1,800	Santa Fe Group undifferentiated unit.	−280	6	Ps	Ca
4.411(G2)	do	Aug. 1951	6,055.6	1,990	do	−259	7	Ps	Ca, L
4.444(G1)	do	July 1950	5,972.8	2,000	do	−192	4.8	Ps	Ca
5.112(G5)	do	May 1951	6,306.1	1,850	do	−411	5.4	Ps	Ca
5.231(G4)	do	do	6,228.8	1,940	do	−347	4	Ps	Ca
13.114(L1)	Los Alamos Canyon	Nov. 1946	5,624	870	do	(1)		Ps	Ca
14.221(L3)	do	May 1947	5,672	870	do	(1)	1.4	Ps	Ca
14.222(L2)	do	Dec. 1946	5,651	870	do	(1)		Ps	Ca
14.312(L6)	do	Dec. 1948	5,770	1,790	do	5(±)	6.9	Ps	Ca
15.434(L5)	do	Sept. 1948	5,840	1,750	do	−71	3.2	Ps	Ca
20.221	Pueblo Canyon	Jan. 1950	6,370.7	642	Puye Conglomerate	−593.1	.2	N	
20.221a	do	do	6,370	225	Basalt of chino Mesa, unit 2	−188		Ws	
22.114(L4)	Los Alamos Canyon	July 1948	5,975	1,965	Santa Fe Group undifferentiated unit.	−189	6.3	Ps	Ca
31.433	Pajarito Canyon	Mar. 1950	6,592	263		Dry			
36.314	Canada Ancha		5,550		Santa Fe Group undifferentiated unit.	(1)		S	Ca

[1] Flowing; head was not measured.

The accumulation of the coarse material in the caldera probably was rapid, because an abundance of loose material was available for deposition in times past. Even today loose debris is abundant on the steep slopes of the domes. Such debris could have been carried readily to the edge of the lake by the melt waters from heavy Pleistocene snows. It is possible also that the lake formed before the emplacement of some of the domes and that the expanding and cracking crusts of the domes may have contributed debris directly to the water.

The mechanisms by which the gravel was carried to the centers of the Valle Toledo and the Valle Grande are unknown. At the very beginning of deposition, much debris may have worked its way readily down steep underwater slopes to the central part of deep basins. Somewhat later, deltalike accumulations may have been built up at the margins of the lake adjacent to the interior domes and the caldera rim. Much debris then may have slumped from the outer parts of these deltalike accumulations and reaccumulated in deeper water, and much pumiceous material may have floated out to deep water and sunk after becoming waterlogged. Also, large quantities of gravel may have been deposited at times when the lake was dry. The beds of clayey silt and silty clay are normal lake sediments and are best developed far out from the steep slopes of the caldera. The thin zones of silt and clay in the Valle Toledo, however, indicate that there were times when little coarse debris was being washed into the depression.

AGE

The lacustrine deposits are of Pleistocene age. Plant spores from the upper 40 feet of sediments in the Valle Grande examined by Paul Sears of Yale University (written communication, 1952) and by Catherine Clisby of Oberlin College (written communication, 1952) are believed to have been deposited in the last 25,000 years.

ALLUVIUM

VALLES CALDERA AREA

Alluvium of Recent and Pleistocene age composes the deposits in the Valles Caldera.

The caldera contains two sets of terraces. The higher and older set occurs as two small sand- and gravel-capped remnants in the southeastern part of the Valle Toledo and one small remnant near the head of the Valle Grande just below the altitude of 8,800 feet. These small remnants are capped by a veneer of sand and gravel that is composed of various types of rhyolitic materials. The remnants and their veneer probably are the remains of lake terraces.

The lower set of terraces is conspicuous adjacent to the streams in both Valle Grande and Valle Toledo. These terraces are related to the streams to which they are adjacent inasmuch as they slope toward the streams, and they slope gradually to lower altitudes downstream. The terraces are capped by beds of silt, sand, and gravel composed chiefly of rhyolitic material. These terrace deposits range in thickness from about 10 to 30 feet.

Alluvial fans, which extend onto and are younger than the low sets of terraces, extend inward from the steep slopes of the caldera rim and away from the interior rhyolite domes. The fans are composed chiefly of sand and gravel but contain much silt. These materials have been derived from the bedrock units from which the fans extend.

Narrow bands of channel alluvium lie below the low terraces and adjacent to the streams in the caldera. The alluvium is composed of clayey to silty sand and gravel that is composed chiefly of rhyolitic debris.

RIO GRANDE AREA

A low terrace in the northeastern part of the area slopes eastward from the Puye Escarpment to the Rio Grande. The terrace deposits are beds of silt, sand, and gravel, probably less than 25 feet thick, which were derived mainly by the erosion of the Puye Conglomerate. These deposits merge eastward into the alluvium of the valley of the Rio Grande and are not differentiated on the geologic map from the channel alluvium.

Channel alluvium extends southward along the Rio Grande as far as about a mile south of Otowi bridge. A patch of alluvium is present just north of White Rock Canyon near the month of Canada Ancha. Channel deposits of alluvium occur also in several of the larger canyons on the Pajarito Plateau. The channel deposits range in thickness from 0 to about 25 feet. Locally they consist of fairly clean sand and gravel, but in most places they contain much silt.

STRUCTURE

GENERAL STRUCTURE

The geologic structure of surface rocks in the Los Alamos area is simple, although the structure of underlying rocks may be complex. Most of the area is within the western part of the Rio Grande structural depression. The regional dip of surface rocks of the Pajarito Plateau is 1°–2° E. Beds of the Santa Fe Group in the easternmost part of the area dip gently to the west.

FAULTS

The rocks of the Pajarito Plateau are broken by several northward-trending normal faults. The Pajarito fault zone lies near the western edge of the plateau in the southern part of the area. The Bandelier Tuff at the southern edge of the area and on the east side of the Pajarito fault is downthrown about 300 feet in relation to the tuff on the west side of the fault. The fault farther north splits into two smaller subparallel faults, both downthrown to the east. Displacement decreases northward until both faults die out. The fault planes dip steeply to the east.

Two other normal faults, en echelon to the Pajarito zone, lie to the northeast. These faults are downthrown to the west, and the fault planes dip to the west also. The westernmost of the faults extends southward for a short distance subparallel to the northern extension of the Pajarito zone; the area between the faults is a shallow syncline. The Bandelier Tuff is displaced about 50 feet on the echelon faults. The Tschicoma Formation along the easternmost fault, however, may be displaced as much as 500 feet. This seems to indicate recurring movement along a pre-Bandelier fault.

Several small faults displace the undifferentiated unit of the Santa Fe Group and Puye Conglomerate in the east-central part of the area near the confluence of Los Alamos and Guaje Canyons. The throw on these faults is only a few feet, but the throw may be more at greater depth because of recurrent movements on these faults during deposition of the undifferentiated unit. The undifferentiated unit of the Santa Fe Group is less permeable in the faulted area.

VALLES CALDERA

The structure of the Valles Caldera is masked for the most part by Pleistocene and Recent fill, and the exact mechanism of its formation, therefore, is not known. The caldera unquestionably was formed by collapse following the eruption of the Tshirege Member of the Bandelier Tuff, however. The thick lake deposits indicate that part of the caldera was a closed topographic depression prior to recent breaching by headward erosion of San Antonio Creek and the East Fork of the Jemez River.

GEOLOGIC HISTORY

The rocks of the Los Alamos area are related to the Rio Grande structural depression, and their history is in large part a history of this depression and its associated volcanism. Pertinent history began after the early stages of formation of the Southern Rocky Mountains. The Rio Grande depression began to form in middle Tertiary time as the result of downfaulting which may have been caused by arching and consequent elongation of the earth's crust during epeirogenic uplift of the region. As the complex depression subsides relative to adjacent highlands, the Santa Fe Group accumulated as fill in the depression. The eruption of the volcanic rocks of the Los Alamos area occurred during subsidence which was accompanied by normal faulting at the west margin of the depression in Pliocene and Pleistocene time.

Sediments of the undifferentiated unit of the Santa Fe Group in the latitude of Los Alamos were laid down as coalescing alluvial fans and alluvial plain deposits in Miocene and Pliocene time. Most of the sidements of the undifferentiated unit of the Santa Fe Group in the Los Alamos area are composed of sand and silt and a minor amount of gravel, and most are poorly consolidated. These sediments were probably deposited on alluvial plains beyond the margins of coarse alluvial fans deposited adjacent to the bounding uplifts. Alternate deposition of coarse fan deposits and alluvial plain deposits of the undifferentiated unit of the Santa Fe Group near the western front of the Sangre de Cristo Mountains may be interpreted to indicate periodic faulting and consequent changes in stream gradient during subsidence of the Rio Grande depression. Basalt flows in the undifferentiated unit of the Santa Fe Group in the Los Alamos area probably were erupted from feeders along faults near the western margin of the depression.

The volcanic rocks of the Jemez Mountains began to accumulate along a fault zone at the western margin of the depression during deposition of the upper part of the undifferentiated unit of the Santa Fe Group. Possibly the first stages of the development of the Jemez Mountains volcanic pile are represented by the deepest beds of basalt penetrated in wells 19.7.4.133 (G3), 5.112 (G5), and 5.231 (G4) in the Los Alamos area. Debris from the latitic flows of the Tschicoma Formation lies above the shallowest basalt flow penetrated in wells 19.7.5.231 (G4) and 5.112 (G5).

As the thick and pasty latite lavas of the Tschicoma Formation were erupted, they flowed eastward into the Rio Grande depression. Some loose material from the flows was washed eastward, where it was mixed with sediments of the undifferentiated unit of the Santa Fe Group that were derived from other areas. Later, after faulting which tilted beds of the undifferentiated unit slightly toward the center of the depression, the ancestral Rio Grande appeared. The Totavi Lentil of the Puye Conglomerate was deposited as channel fill on the undifferentiated unit. Deposition of the Totavi was contemporaneous with some of the Tschicoma eruptions as the beds of gravel interfinger with latite flows at places along the western margin of the old river channel. The overlying fanglomerate member of the Puye was deposited as an alluvial fan, apparently as the latite flows reached the climax of their development, probably in late Pliocene time. C. S. Ross and R. L. Smith (oral communication) also observed that the Puye and flows of the Tschicoma Formation interfinger north of the Los Alamos area and the materials of the fanglomerate, including the water-washed pumice and laharic debris, are detritus derived from the latitic eruptions of the Tschicoma Formation. The pyroxene andesite of the Tschicoma Formation was erupted somewhat later.

While the coarsely porphyritic latitic rocks were being erupted near the west margin of the Rio Grande depression and were pouring eastward into the depression, basaltic rocks were being erupted in the interior of the depression in the region southeast of the Los Alamos area. Units 1 and 2 of the basaltic rocks of Chino Mesa were erupted contemporaneously with the deposition of the Puye Conglomerate. The eruptions were probably contemporaneous in part with faulting in the interior of the depression, and, in part, were probably younger than this faulting, inasmuch as small faults displace sediment of the undifferentiated unit but do not cut the overlying flows of unit 1. Older and older flows of unit 1 appear southward in White Rock Canyon, and it is probable that the undifferentiated unit of the Santa Fe was tilted to the south during the initial stages of the basaltic eruptions. During the eruptions of units 1 and 2, and probably during deposition of the fanglomerate member of the Puye, the upper tongue of the undifferentiated unit was deposited above the Totavi Lentil in the area at the north end and east of the present White Rock Canyon. These sediments indicate that the Rio Grande depression was still receiving detritus from the easterly bounding block of the depression (the Sangre de Cristo block) during Puye time. Beds of gravel in the upper body of the undifferentiated unit of the Santa Fe Group may have been the earliest channel deposits of the ancestral Rio Grande, slightly older than the Totavi Lentil, which apparently was displaced eastward by the volcanic flows and fanglomerate of the Puye.

A period of erosion followed the eruption of the flows of unit 2 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 expressed adjacent to Guaje Canyon between wells 19.7.4.444 (G1) and 5.112 (G5). Later, possibly toward the end of this cycle of erosion, the pediment was partly dissected and a lower surface was cut on the Puye near Totavi. The relation between the two surfaces is curious, but it appears that the lower surface was developed in the last stages of the cutting of the higher surface as the Rio Grande shifted westward locally. Both surfaces probably are parts of Kirk Bryan's Ortiz pediment (1938, p. 215).

Following this important cycle of erosion, the last three units of the basaltic rocks of Chino Mesa were erupted. Unit 3 was erupted as steep-sided masses on the pediment surface, and the flow of the Rio Grande was partly blocked. The old alluvium near Totavi and elsewhere was deposited behind these basalts during the partial damming of the river. A short time later, two basalt flows (unit 4) entered the area from centers to the southeast. Then, after a short period of erosion, the cinder cones, local flows, and a dome of basalt, all composing unit 5, were erupted. Subsequently, a deep canyon, lying west of the Rio Grande in the southeastern part of the area and now filled by Bandelier Tuff, was cut.

The last major phase of igneous activity in the area is represented by the rocks of the Tewa Group. The eruptions began when a rhyolitic magma worked upward beneath the central area of the Jemez Mountains volcanic pile. Upward movement of the magma eventually fractured the overlying rocks, exposed the upper part of the magma to atmospheric pressure, and explosions motivated by the vapor pressure of the melt ejected pumice. This pumice was thrown high into the air and dropped as ash-fall material to form the fairly prominent Guaje Member of the Bandelier Tuff. Diffusion of water and its separation as vapor within the upper levels of the melt may have played a part in causing the series of explosions which formed the bedded Guaje Member. Then perhaps with a vent well opened, the remaining magma surged upward, and driven by escaping and expanding volatiles, great volumes of pumice were erupted. This pumice, possibly coming from a slightly less water rich melt than the upper part of magma which gave rise to the Guaje Member, was not thrown high into the air but instead swept down the flanks of the volcanic pile as a granular pumice flow. This debris was mobile and rushed across the Pajarito Plateau on a gradient of about 100–150 feet per mile, but it did not have sufficient heat to weld, even where it is 215 feet thick and fairly close to its point of eruption. The pumiceous aggregate and a very few thin beds of ash-fall pumice at the top constitute the Otowi Member of the Bandelier. Some collapse of the crater area into the underlying void must have followed (C. S. Ross and R. L. Smith, oral communication); this would have formed the elliptical-shaped caldera described on page 57. Following this collapse, a part of the viscous volatile-poor magma was extruded to form the domes of Cerro Toledo Rhyolite.

Somewhat later, during a period of erosion on the Pajarito Plateau, the Cerro Rubio Quartz Latite domes were intruded in the central part of the volcanic pile. Final activity was approaching by this time.

Again 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 was first ejected. At no place is this ash fall as thick as the pumice of the Guaje Member. The thin beds of pumice were immediately followed by large quantities of pumiceous ash and pumice that swept across the gently sloping Pajarito Plateau as ash flows. Apparently two or possibly three flows of ash were erupted in rapid succession. Unlike the cycle that gave rise to the Guaje-Otowi eruptions, this material carried sufficient heat with it to crystallize and weld the ash and pumiceous matter almost completely. Most of the Tshirege Member of the Bandelier was consolidated as a result of welding and crystallization. A very little ash-fall pumice at the top of the Tshirege Member, and noted only in the foundations of some of the large buildings at Los Alamos, is a result of final explosions of minor magnitude which immediately followed the hot ash flows. It is noteworthy that the culminating cycle of eruptions followed exactly the same pattern as the Guaje-Otowi eruptions. The ash flows of the culminating cycle, however, contained larger proportions of ash-size material, smaller and less numerous lumps of pumice, and were hotter. The author believes that these differences were caused by two main factors: (1) the melt of the culminating cycle probably contained less water; hence the magma temperature was somewhat higher; and (2) the melt of the culminating cycle probably was closer to the surface when the eruptions began; hence less work was done in lifting the tuffaceous debris to the surface and therefore there was less heat loss before the particles reached the crater area. The relatively small amount of ash-fall pumice at the beginning of the Tshirege cycle seems fairly convincing evidence that the melt of this eruptive cycle contained less water.

After formation of the Valles Caldera by collapse following the Tshirege eruptions in middle or late Pleistocene time, the domes of Valles Rhyolite were extruded within the caldera, and the main eruptions of the final eruptive cycle came to an end. There has been only minor post-caldera activity since the Valles Rhyolite, and this activity has been west of the Los Alamos area.

The last geologic events in the area were faulting on the Pajarito Plateau, filling and draining of the lake in the Valles Caldera, and the erosion that cut the canyons of the area. A lake occupied parts of the Valles Caldera in the latter part of Pleistocene time, but it was drained eventually by the headward erosion 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

SURFACE WATER IN THE VALLES CALDERA AREA

Water of good quality emerges at several places in the eastern part of the Valles Caldera west of Los Alamos. Many seeps and a few small springs discharge along the coalescing alluvial fans that extend inward from the steep slopes of the caldera rim and outward from the rhyolite domes. Other seeps and one or two springs are associated with the low terraces that are adjacent to the stream channels. Springs also emerge from the edge of rhyolite domes. These springs are all small and individual flows range from about 1 to 10 gpm (gallons per minute). Most of the ground water discharged by seeps and springs in the caldera issues at low points along the stream channels.

The springs and seeps associated with the alluvial fans are most noticeable late in the spring when lush grass around them is the first to turn green. The seeps also are 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.

Seeps discharge at the edges of the low terraces and some discharge at low spots on the surface of these terraces. The aggregate discharge from several seeps forms tiny streams in a few places, particularly in the spring of the year. Spring 20.4.14.424, in the Valle Toledo, flows about 2 gpm from the edge of a terrace. Most of the channel deposits are waterlogged below the terrace escarpments and adjacent to main drainage ways. In part, at least, this water is discharged from debris on the terraces and emerges at the base of the terrace escarpments.

Springs 19.4.2.144 and 12.341, each flowing less than 5 gpm, emerge near the southwest and west base of a large rhyolite dome (Cerro del Medio). The water soaks into the upper slopes of the adjacent fan.

The largest springs are along the stream channels. San Antonio Creek is a perennial stream in the Valle Toledo, appearing as a small spring or seep, 20.5.30.211, at the head of the valley. The flow is 100 gpm about a mile downstream from the spring and increases to about 300 gpm just above the point where the creek enters a narrow gorge cut in Valles Rhyolite. A spring area, 20.4.14.300, discharges about 800 gpm from blocky pumiceous rhyolite in the narrow gorge near the west end of the valley. Records for the gaging station, San Antonio Creek near Los Alamos, N. Mex., located at the mouth of the gorge, show that the minimum sustained flow approximated 1,100 gpm during the period June 1949 to September 1950.

Perennial flow of the East Fork of the Jemez River in the Valle Grande heads at a spring area 19.5.18.430. This flow, approximately 900 gpm, emerges from fractured Valles Rhyolite at the southeast point of Cerro del Medio. Downstream, between the springs and the point where Jaramillo Creek enters the East Fork, the base flow increases. The flow in the East Fork of the Jemez River is increased by about 500 gpm from Jaramillo Creek, which heads west of the Los Alamos area and flows across a part of the Valle Grande before reaching its confluence with the East Fork of the Jemez River. La Jara Creek also contributes its flow to that of the main stream. The flow of the East Fork of the Jemez River may increase still more toward the west end of the Valle Grande, a short distance beyond the Los Alamos area.

The flows of San Antonio Creek and the East Fork of the Jemez River are fully appropriated. Indians living downstream on the main stem of the Jemez River have a primordial right to this surface flow for use in irrigation.

GROUND WATER IN THE VALLES CALDERA AREA

Sixteen holes were drilled to test the general character and extent of the water-bearing material during the summer and fall of 1949. Holes 20.4.13.144, 14.443, 24.213, 24.213a, 24.214, and 20.5.19.333 were drilled in the Valle Toledo; holes 19.4.13.341, 26.222, 19.5.17.223, 19.133, 19.134, 19.134a, and 19.424 were drilled in the Valle Grande; and holes 19.5.4.111, 20.5.33.312, and 34.233 were drilled along the east side of the caldera. The Valle Toledo and Valle Grande holes were cased and equipped for discharging-well tests to determine the hydraulic characteristics of the fill in the valleys. Wells 19.5.4.111, 17.223, 20.5.33.312, and 34.233 were abandoned, as they appeared to have penetrated only material of low permeability.

VALLE TOLEDO

Both water-table and artesian conditions exist in the Valle Toledo. Water-table conditions exist in the outlying areas immediately beneath the fans and the outer parts of the terraces. Measurements of water levels in the six test holes indicate that an artesian reservoir underlies most of the terrace areas in Valle Toledo. Records of these holes indicate that the unconsolidated material in the caldera is as much as 500 feet thick in Valle Toledo and is underlain by domes of the Valles and Cerro Toledo Rhyrolites. Schematic diagrams of the Valle Toledo (figs. 17, 18) show the extent of the aquifer, the direction of water movement, recharge and discharge areas, and the piezometric surface (the height to which water will rise in wells or bore holes) of the artesian water.

The piezometric surface is above the ground surface in areas lower than the terraces (fig. 18) adjacent to the stream channel, and wells drilled in these low-lying areas into the artesian reservoir yield water under sufficient head to flow 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 the springs and to some extent toward San Antonio Creek (fig. 18).

Artesian head increases with depth in the test holes near the center of the valley; the pressure increases beneath successive beds of the silty to clayey material in the aquifer which act as partial confining units. Some of the artesian water moves upward through the fill and feeds San Antonio Creek in its course through the valley. In hole 20.4.13.144, the head in the upper part of the aquifer was greater than in the lower part, indicating that in outlying parts of the valley the ground water is moving downward as well as laterally.

The strong flow caused by a combination of permeable material and artesian head in the central part of the valley made well construction difficult in some areas. Hole 20.4.14.443 was almost lost during construction because of the strong flow of water. At site 24.214, the head was more than 30 feet above ground, and two holes were lost when they began to flow at about 2,000 gpm (gallons per minute). A third hole completed and developed as a well flowed about 3,000 gpm. A discharge of this magnitude, however, would not continue indefinitely. The water available to wells in the Valle Toledo over a period of years would be approximately equivalent to the natural discharge in the valley, which is about 1,000 gpm.

VALLE GRANDE

The test holes tapped another artesian reservoir in the Valle Grande. This is the largest valley of the caldera and the unconsolidated material is thicker and more extensive than elsewhere in the caldera. The total thickness of the saturated fill is a matter of conjecture because none of the holes penetrated bedrock. The fill in a large part of the valley may be as much as 2,000 feet thick and probably is thickest in the central, southern, and eastern parts of the valley. The fill probably thins to the north, as it laps against the rhyolite of Cerro del Medio in the subsurface. The lower part of the fill in the Valle Grande probably is tuff.

Hole 19.5.19.134, the deepest hole drilled in Valle Grande, penetrated almost 300 feet of clay and silt that form the upper confining unit for the artesian aquifer in the valley and then penetrated nearly 900 feet of pumiceous sand and gravel that form the aquifer. Information obtained from the outlying holes 19.4.13.341, 26.222, and 19.5.19.424 indicates that the clay and silt confining unit is thickest in the central part of the valley and that it interfingers with coarser clastic rocks toward the edges of the valley.

Water-table conditions exist in the fan and terrace deposits of the outlying areas, but the water is confined in most of the valley. (See fig. 19). Judging from data obtained from holes 19.5.13.341 and 19.424, the piezometric surface may be as much as 30 feet below the land surface in the higher parts of the terrace areas. Along the lowest parts of the valley adjacent to the main drainage, the piezometric surface ranges from near ground level at the main springs 19.5.18.430 in the upper part of the valley to more than 25 feet above ground at hole 19.4.26.222 in the lower part of the valley.

The movement of water through the aquifer in the Valle Grande is less well known that that in the Valle Toledo, although the several test holes and the measurements of discharge of the streams and springs furnish much information. The greatest movement is toward the main spring area 19.5.18.430, as is indicated by the proportion of the flow of that spring area to the total flow of the streams. Movement toward Jaramillo Creek probably is relatively small, although this creek may gain as much as 500 gpm in its course through the Valle Grande.

The movement of water laterally through the fine-grained unconsolidated sediments in the central part of the valley must be relatively slow, because the gradient of the piezometric surface is low. The maximum difference in altitude of the water levels in the widely scattered holes is only 24 feet, and the piezometric gradient between hole 19.5.19.134 and 19.4.26.222 is only 2 feet per mile. Downward movement of water in places in the aquifer is indicated by the greater head at the top of the aquifer than the head at the bottom of holes 19.4.13.341 and 26.222. Thus, 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. The East Fork of the Jemez River is a gaining stream in the Valle Grande, and some of this gain is probably water rising from depth to the bed of this stream.

RECHARGE, MOVEMENT, AND DISCHARGE

The ground-water reservoir in the eastern part of the Valles Caldera is recharged from precipitation in the caldera. A small fraction of the precipitation escapes evaporation and transpiration and percolates downward to the ground-water reservoir. Most of the infiltrated water follows an indirect course to the caldera fill, passes through it laterally, and emerges along the main drainage. Some, however, feeds the small springs and seeps along the fans and terraces. (See figs. 17–19.)

The ground-water reservoir in the Valles Caldera is recharged chiefly from precipitation on the steep slopes of the interior domes, on the inward-facing escarpment of the caldera rim, and on the alluvial fans adjacent to steep-sided features. Some precipiation, in part melt water from snow and in part rain water, enters the crusts of the volcanic domes. The domes of Valles Rhyolite have highly fractured, rubble covered, and commonly pumiceous crusts, and probably constitute the major areas of intake. Much water is absorbed by these crusts and transmitted downward. In a few places, percolating ground water reaches less permeable rhyolite in the outcrop area of the domes and is discharged by springs. In general, however, the water moves farther downward before it reaches the less permeable rock of the interior of the domes. This less permeable rock deflects the downward percolation, and the water moves laterally to the surrounding alluvial fans and caldera fill. Precipitation on the rubble resting on the steep escarpment of the caldera rim moves downward only a very short distance before it reaches the impermeable rocks of the Tschicoma Formation of Cerro Toledo Rhyolite and is deflected to the adjacent fill or fan material.

The ground-water reservoir is recharged additionally by infiltration of water from rivulets that enter the upper slopes of alluvial fans from the adjacent slopes of the domes and rim. Rivulets from two small springs discharging on the lower slopes of a rhyolite dome on the north side of the Valle Grande reach the upper slopes of fan material and soak in immediately. Rivulets that form on the steep slopes from melting snow in the spring and after heavy rains in the summer probably contribute to the recharge of the ground-water reservoir as they pass across the fans. This recharge probably is concentrated in a narrow strip on the upper parts of the fans, where the fan material is coarsest. The vertical permeability of the fan material evidently is not enough to transmit all the absorbed water downward to the fill. Some of the water that enters the fans is deflected laterally, and this rejected recharge emerges on the slopes of the fans as seeps and springs.

Water moving through the fan material follows two main courses. Some of the water moves downward to the caldera fill and some moves laterally into the alluvium of the low terraces. For the most part, the water that reaches the terrace deposits is discharged at the edges and at low points on the terraces. In places, however, where terraces far from the main drainage extend to higher altitudes, some water probably moves downward through the terrace gravel and into the underlying caldera fill.

Water recharging the ground-water reservoirs in the Valle Toledo and the Valle Grande moves slowly through the fill to natural outlets along the main streams. The quantity of water discharged at these natural outlets is equal approximately to the recharge.

AQUIFER HYDRAULIC COEFFICIENTS

The coefficient of permeability of a material is expressed as the gallons of water per day that will pass through a cross section of 1 sq ft of material under a unit hydraulic gradient, or through a section 1 ft high and 1 mile wide under a gradient of 1 ft per mile. A summation of the coefficients of permeability for the full thickness of the aquifer would be equal to the coefficient of transmissibility. The coefficient of transmissibility is expressed as the gallons of water per day that would pass through a vertical strip of aquifer 1 ft wide extending the full height of the aquifer under unit hydraulic gradient or through a section of aquifer 1 mile wide, extending the full thickness of the aquifer, and under hydraulic gradient of 1 ft per mile. The coefficient of permeability of each foot of aquifer cannot be determined under field conditions, but the coefficient of transmissibility can be determined by controlled pumping tests. The coefficient of permeability calculated by dividing the coefficient of transmissibility by the aquifer thickness is an average and necessarily may not be indicative of the coefficient of permeability of any particular 1-ft section of the aquifer.

The coefficient of storage of an aquifer is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Pumping tests were made on wells in the Valle Toledo and Valle Grande to determine the hydraulic characteristics of the aquifers, and the amount of interference that pumping of wells would cause on the discharge of springs along the streams.

The tests were described and interpreted by Theis, Conover, and Griggs (1960). They concluded that the coefficient of transmissibility of the aquifer in Valle Toledo is about 50,000 gpd (gallons per day) per ft and that of Valle Grande is 25,000 gpd per ft or higher. The coefficient of storage is about 0.005 for the aquifer in the Valle Toledo; a coefficient of storage was not computed for the Valle Grande.

EFFECT OF WELLS ON GROUND-WATER REGIMEN

Theis, Conover, and Griggs (1960) concluded that the withdrawal of ground water by wells in Valle Toledo and Valle Grande would decrease the flow of springs in those valleys and would dry up the springs if the annual withdrawal was sufficiently large. The average annual recharge is equal to the average annual spring discharge, therefore the quantity of water available to wells, on a long-term basis, would be the quantity that issues from springs. This would amount to about 1,600 and 2,200 acre-feet per year from the Valle Toledo and the Valle Grande, respectively. These values probably would have to be revised if longer records of streamflow were available.

Theis, Conover, and Griggs (1960) estimated that lowering the ground-water level 100 feet in the Valle Toledo would yield about 20,000 acre-feet from storage. Although the area of the Valle Grande is about twice that of the Valle Toledo, the thick clay bed in the Valle Grande would limit the quantity of water yielded from storage. It is estimated that the same amount of water level lowering in each valley would yield about equal amounts from storage from each valley.

CHEMICAL QUALITY OF WATER

BY J. D. HEM

In the course of studying the chemical quality of ground water and surface water in the Valles Caldera area, samples of water were obtained from the springs along San Antonio Creek and the East Fork of the Jemez River and from the flow of the two streams. Samples also were obtained from the flowing test wells drilled in the Valle Toledo and the Valle Grande areas. Selected analyses of these samples are listed in table 3.

VALLE TOLEDO

In general, the ground waters of this area are soft and contain low concentrations of dissolved solids. None of the samples contained more than 143 ppm (parts per million) dissolved solids or more than 42 ppm equivalent $CaCO_3$—hardness. In most of the samples, silica constituted half or more of the dissolved solids (40–60 ppm). The predominant anion in all the samples was bicarbonate, and, in most samples, more than half the total cations were sodium. The dissolved matter was derived slowly from action of ground water on the relatively inert volcanic rocks.

The ground waters of the Valle Toledo area differ from those of the Valle Grande area by one major respect. Most waters from the Valle Toledo contain rather large amounts of fluoride. Several samples contained 3.6 ppm of this constituent, and many more of the samples contained 2.0 ppm or more.

Some indication of the differences in chemical quality between the shallow water and the water at depth in the caldera fill was determined by comparing the analyses of the water taken from the 2-inch pipe and the 6-inch pipe of the observation wells. Theoretically, the upper part of the aquifer was sampled by collecting water flowing from the 6-inch pipe, and the lower part of the aquifer was sampled by collecting water flowing from the 2-inch pipe. The seal between these two

TABLE 3.—*Records of selected springs in the Los Alamos area, New Mexico*

Location	Topographic situation	Issues from	Altitude above mean sea level (feet)	Flow (gpm)	Remarks
Valles caldera area					
19.4.2.144	Base of rhyolite dome	Valles Rhyolite	8,750	<5	
12.341	do	do	8,726	<5	
19.5.18.430	do	do	8,520	900	Several springs composing a spring area.
20.4.14.300	do	do	8,560	800	Do.
14.424	Edge of terrace	Alluvium	8 630	2	
20.5.30.211	Steam channel	Fan deposits	8,760		Head spring in San Antonio Creek.
Rio Grande area					
18.7.20.312	Canyon bottom	Totavi Lentil, Puye conglomerate.	5,700	50	
19.5.12.143	do	Talus and alluvium	8,000	20	
14.431	do	do	8,600	25	
25.111	Canyon wall	Tshirege Member, Bandelier Tuff.		4	
25.333	Canyon bottom	do	8,000	90	
26.221	do	Talus and alluvium	8,240	4	
26.332	do	Undifferentiated latite, Tschicoma Formation.	8,216	2	"Armstead Spring."
35.144	do	Tshirege Member, Bandelier Tuff.	8,280	5	"American Spring."
20.5.26.113	do	do	8,850	25	
26.311	do	do	8,840	40	
35.433	do	Talus	8,660	15	

pipes was not perfect, and some mixing of the shallow and deep water occurred within the wells below the sampling points.

Samples from the observation wells have only minor differences in quality that could be attributed to the effect of depth. Water from well 20.4.24.214, when 97 feet deep, contained only 0.6 ppm fluoride; at a depth of 478 feet it yielded water having 1.4 ppm fluoride; and at a depth of 652 feet it yielded water having 2.4 ppm fluoride. A sample collected from this well after a period of heavy pumping contained 3.6 ppm fluoride. These data indicate that fluoride concentration in the fill increases with depth. The deeper zones of saturation are subject to less flushing and replacement with recharge from rainfall; thus, it is logical to expect that concentrations of ions such as fluoride might be greater in the deeper zones.

Samples of water were collected from time to time from the spring area 20.4.14.300 near the west end of Valle Toledo. This water was similar in quality to that from wells in Valle Toledo, and all the samples contained at least 1.8 ppm fluoride. Surface water collected from San Antonio Creek at location 20.4.14.433 at the west end of Valle Toledo was practically identical in quality with that from the springs.

The close resemblance of the quality of the water from wells, springs, and San Antonio Creek emphasizes the hydraulic interconnection of all water in this area. It provided further evidence that withdrawals of water from wells will reduce surface discharge from the area, because the wells and springs are supplied by the same aquifer system.

VALLE GRANDE

Chemical analyses data of water from four test wells in Valle Grande are given in table 4. The water in the Valle Grande area, as indicated by these analyses and those of spring flow and surface water, has a low dissolved-solids content (100–150 ppm) and equivalent $CaCO_3$ (about 25 ppm of hardness). The silica content is high (60–75 ppm) and constitutes about half of the total mineral content. The waters resemble those in Valle Toledo closely except that none of the water samples from Valle Grande contained more than 0.8 ppm fluoride. Samples from the upper and lower parts of the water-bearing zone in well 19.5.19.133 are not significantly different.

The quality of water from the spring area 19.5.18.430 near the head of the perennially flowing part of the East Fork of the Jemez River closely resembles that from wells in Valle Grande. The spring water, however, contains slightly less dissolved solids than most of the well water.

RELATION TO USE

The quantity of dissolved solids and the hardness of water from the Valle Toledo and the Valle Grande areas are within acceptable limits for most uses, and the water is of excellent quality in these respects for domestic or industrial use. The relatively high content of silica, however, would contribute to scale formation when the water is heated and would be objectionable to steam-power installation. Under some conditions, the water from this area may be corrosive to metal.

The fluoride content of water for domestic use has received considerable attention in recent years. It is recognized generally that water containing more than about 1.5 ppm of fluoride may cause mottling of the teeth of children drinking such water during the time the permanent teeth are forming. On the other hand, 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 [California] State Water Pollution Control Board 1957, p. 257.

The concentration of fluoride in water from the Valle Toledo is so high that its use as a sole source for a public water supply is objectionable. The water from the Valle Grande has a much lower fluoride concentration. An equal mixture of waters from Valle Toledo and Valle Grande should result in a fluoride concentration that is nearly optimum.

TABLE 4.—*Chemical analyses of water from the Los Alamos area, New Mexico*

[Results in parts per million except as indicated]

Location	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and potassium (K) as Na	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	Dissolved solids	Specific conductance (micromhos at 25°C)	Remarks
Valles caldera area																	
19.4.26.222	10-26-49	------	75	0.57	13	2.4	19	87	------	9.3	2	0.2	0.3	42	165	157	From 6-inch casing.
19.5.18.430	6-20-50	------	60	------	6.0	2.0	11	48	------	2.1	1.5	.8	.5	23	108	84	Flow from a spring.
19.133	10-26-49	------	74	.53	6.0	2.2	19	73	------	2.5	1	.6	.3	24	142	126	From 6-inch casing.
19.133	do	------	66	.02	8.0	1.6	18	64	------	8.2	2	.4	.2	26	136	110	From 2-inch casing.
19.134	6-20-50	------	71	------	6.0	2.1	11	49	------	2.4	1.5	.2	2.4	24	121	94	
19.134a	10-26-49	------	70	.02	10	2.7	16	57	9	4.1	2	.4	.3	8.6	142	109	Do.
20.4.14.300	7-6-49	------	55	.01	6.0	.9	11	38	------	2.1	2	2.4	.3	18	98	80	Flow from a spring area.
14.433	6-20-50	------	60	------	7.2	.6	12	45	------	2.1	1.8	2.2	.2	20	108	86	San Antonio Creek.
14.443	10-16-49	------	39	2.1	10	1.6	7.6	42	------	3.5	3	2.0	.9	32	90	85	From 6-inch casing.
24.213	do	------	51	1.6	8.5	.9	15	48	------	3.7	2	3.6	.9	24	111	86	Do.
24.213	do	------	49	.03	10	.4	11	43	------	2.9	2	3.6	.8	26	101	88	From 2-inch casing.
24.213a	do	------	45	.08	15	1.1	16	49	14	3.3	1	2.8	.8	42	123	107	From 6-inch casing.
24.213a	do	------	53	.19	10	.7	11	45	------	2.7	1	3.6	.8	28	105	84	From 2-inch casing.
24.214	7-6-49	50	62	.01	5.1	1.2	11	42	------	2.6	1.5	.6	.5	18	105	78	Well depth 97 feet.[1]
24.214	do	55	59	.01	6.0	.9	9.4 1.8	40	------	2.6	1.5	1.4	.5	18	103	80	Well depth 478 feet.[2]
24.214	7-27-49	62	59	.09	11	2.5	19	68	------	13	2	2.4	.5	38	143	122	Well depth 652 feet.
24.214	9-20-49	64	57	.07	10	.4	12	42	------	4.3	2	3.6	.7	26	111	91	Do.
20.5.19.333	10-16-49	------	54	.02	10	1.9	16	70	------	3.3	2	1.6	.2	33	124	100	From 6-inch casing.
20.5.19.333	do	------	59	.02	8.5	1.4	12	51	------	2.5	2	2.0	.5	27	113	91	From 2-inch casing.
Rio Grande area																	
19.7.4.133(G3)	4-1-52	82	56	.02	13	2.1	25	103	------	4.8	3.0	.3	.9	41	156	172	
4.411(G2)	3-29-52	85	54	.03	13	1.4	54	166	------	8.2	4.8	1.4	1.0	38	220	281	
4.444(G1)	4-4-52	78	66	.01	13	1.1	25	97	------	4.9	3.5	.3	1.0	37	163	169	
5.112(G5)	4-1-52	78	46	.01	19	4.4	12	96		4.4	4.5	.3	1.5	66	139	176	
5.231(G4)	6-7-51	79	50	.02	16	2.6	19	96	------	4.9	4.5	.3	1.2	50	146	177	
13.114(L1)	5-14-52	63	27	.03	7.4	1.0	80	177	------	20	18	1.3	1.8	22	244	383	
14.221(L3)	do	58	32	.01	16	.5	32	117	------	7.5	4.0	.5	1.4	42	152	200	
14.222(L2)	do	65	30	.01	5.8	1.0	84	185	------	18	18	2.0	1.3	18	251	379	
14.312(L6)	do	78	30	.02	2.9	.4	63	138	10	6.9	4.0	1.3	1.4	8	188	273	
15.434(L5)	do	62	36	.01	10	.5	54	140	10	6.9	3.0	.7	1.5	27	192	254	
22.114(L4)	do	73	36	.01	9.2	.3	27	91	------	3.5	2.5	.3	.8	24	125	151	
36.314	9-19-51	63	30	------	4.0	1.3	53	106	14	10	4	.2	4.1	16	173	251	

[1] Well was plugged and abandoned after being replaced by a deeper well; both wells are referred to under the same well No.
[2] Well replaces a shallow well having same well No.

A water supply that might be developed in either Valle Grande or Valle Toledo should have a chemical quality similar to that of the headwater springs discharging from these areas into the East Fork of the Jemez River and San Antonio Creek.

SURFACE WATER IN THE RIO GRANDE AREA

The surface waters of the Rio Grande drainage within the Los Alamos area consist of the Rio Grande, 10 miles east of Los Alamos, and the few small springs and streams on the eastern slope of the Sierra de los Valles, just west of Los Alamos. The Rio Grande is the master stream in the region. It has a drainage area of more than 14,300 square miles in the region north of Los Alamos, in north-central New Mexico and south-central Colorado. The average discharge of the Rio Grande for 48 years of record (intervals from 1895–1951) at Otowi bridge at the north end of White Rock Canyon is 1,682 cfs (cubic feet per second) (Paulsen, 1951, p. 296). The minimum daily discharge at this point for the period 1930–51 is 128 cfs, recorded in 1934.

The flow of the springs and streams on the eastern slope of the Sierra de los Valles is very small in comparison to that of the Rio Grande. The largest perennial flow in a stream in the Sierra de los Valles is in a reach of Guaje Canyon. The observed low flow at this place during 1951–52 was approximately 140 gpm during dry periods. The smallest spring, Armstead Spring 19.5.26.332 in Water Canyon, discharges about 2 gpm.

The base flows in the upper reaches of the major canyons on the eastern slope (Guaje, Los Alamos, Pajarito, Canon de Valle, and Water Canyons) discharge from perched water zones in the rocks of the Tschicoma Formation and the Bandelier Tuff. The water in several of the canyons is impounded behind small dams and drains into pipelines for use by the town of Los Alamos. The amount of water collected per unit of drainage area is not uniform in the four canyons containing dams in the streambeds. This is primarily the result of the small size of the dams, which are not capable of storing torrential flows.

The waters of the Rio Grande are fully appropriated and none is available from that source for use in the Los Alamos area except by purchase of water rights. Waters from the small streams and springs on the mountain slope west of Los Alamos have been appropriated for use in the Los Alamos area. As all the water is in or close to the five major canyons, these sources are referred to as the Guaje, Los Alamos, Pajarito, Canon de Valle, and Water Canyon sources.

GUAJE CANYON

Guaje Canyon yields approximately 200,000 gpd during the driest months of the year and is the largest and most reliable source of water from the canyons. The maximum flow collected during the period of snowmelt runoff in the late spring is approximately 500,000 gpd according to records available in 1952. The water is collected behind a small concrete dam 25 feet long and 11 feet high at location 20.6.31.114. This structure is at an altitude of 8,020 feet in Guaje Canyon and has a storage capacity of about 250,000 gallons of water. The drainage area above the dam is about 4½ square miles, and the perennial flow of the stream heads at two springs, about 2½ miles upstream from the structure. Both springs issue from beds of pumice at the base of the Tshirege Member of the Bandelier Tuff. Spring 20.5.26.113 is in the main stem of the canyon, at an altitude of 8,850 feet, and flowed about 25 gpm in 1951–52. Spring 26.311 is in a small branch canyon a short distance south of the main canyon, at an altitude of 8,840 feet. It flowed about 40 gpm in 1951–52. Downstream from the springs to a point about half a mile above the dam, the streamflow is increased gradually by water seeping from the base of talus adjacent to the south side of the streambed.

LOS ALAMOS CANYON

The flow in Los Alamos Canyon is impounded at location 19.5.13.221, at an altitude of 7,660 feet, by a small earthfill dam with a concrete core. The structure is about 35 feet high and can impound more than 10 million gallons of water. The drainage area above the dam is approximately 6 square miles. The flow collected, however, is considerably less than that in Guaje Canyon. The minimum inflow in dry months is about 50,000 gpd according to records available in 1951–52. In the spring, when snow is melting, it has exceeded 200,000 gpd. The base flow in large part is the combined discharge of two small springs. Spring 20.5.35.433 is adjacent to Quemazon Canyon at an altitude of 8,660 feet. The water emerges from talus, and the discharge was about 15 gpm in 1951–52. Spring 19.5.12.143 is adjacent to the main stem of the canyon, at an altitude of 8,000 feet. The spring emerges from talus and alluvium and flowed about 20 gpm in 1951–52.

PAJARITO CANYON

The flow in Pajarito Canyon is diverted by an earth and rockfill dam at 19.5.24.221 at an altitude of 7,920 feet. The structure is 6 feet high and 16 feet long. The drainage area behind this dam is about 1½ square miles, and the minimum flow is about 35,000 gpd according to records available in 1952. The flow collected during the snowmelting period in the spring has been as high as 180,000 gpd. The base flow is fed by a small spring area 14.431 at an altitude of 8,660 feet; the water emerges from alluvium and talus in the floor of the canyon.

CANON DE VALLE

This is the smallest of the surface-water sources. The base flow is only about 10,000 gpd and collects behind a low earth and rockfill dam about 4 feet high and 15 feet long. This structure is in Valle Canyon at an altitude of 8,240 feet. It is immediately below a small spring 19.5.26.221 that flowed about 4 gpm from alluvium and talus in 1951–52. The drainage area of the canyon above the dam is about 2 square miles. The other half of the flow is collected from a small spring on the north wall of the canyon at 25.111, 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 4 gpm is collected behind a bulkhead. During the spring runoff, as much as 140,000 gpd has been collected from these springs according to records available in 1952.

WATER CANYON

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, 19.5.25.333, is at an altitude of 8,000 feet in a short northern branch of Water Canyon. At this point about 90 gpm flowed in 1951–52 from fractures in the Tshirege Member of the Bandelier Tuff; the flow is collected behind a bulkhead placed in the tuff. The other two springs are both small. American Spring 35.144 is a short distance south of Water Canyon, at an altitude of 8,280 feet. The water emerges at the contact of latite of the Tschicoma Formation and the overlying Tshirege Member of the Bandelier Tuff. The flow of about 5 gpm is collected in a concrete spring box constructed around the opening. Armstead Spring 26.332, the smallest of the three springs, is adjacent to the floor of Water Canyon, at an altitude of 8,216 feet. The flow of about 2 gpm emerges from fractures in latite of the Tschicoma Formation and is collected in a concrete spring box.

GROUND WATER IN THE RIO GRANDE AREA

TSCHICOMA FORMATION

The Tschicoma Formation is a poor aquifer. The small quantity of ground water that emerges naturally on the slopes of the Sierra de los Valles indicates that the Tschicoma does not contain large bodies of perched water at altitudes above the floors of the deep canyons cut

722–218 O—64——7

in the formation. In spite of the deep canyons in the outcrop area of the Tschicoma, the base flow (fed by ground water) of streams on the eastern mountain slope is small. Two test holes failed to indicate large ground-water reservoirs at depth. Hole 19.6.17.234, in Los Alamos Canyon, drilled to a depth of 2,000 feet, penetrated the top of the main zone of saturation in the Puye Conglomerate interbedded with the Tschicoma Formation at about 1,200 feet. The water-saturated rocks penetrated by the hole were relatively impermeable and would yield only small amounts of water to the well. Hole 9.443, about a mile northeast of hole 17.234, was drilled to a depth of 1,205 feet. Water-bearing breccia of the Tschicoma Formation was penetrated in the interval 1,184–1,205 feet. A coefficient of transmissibility of 1,000 gpd per ft computed from two pumping tests at hole 9.443 indicated that the aquifer is relatively impermeable and would yield water only at a slow rate to wells.

BANDELIER TUFF

The Bandelier Tuff lies well above the main water table, but in places it contains bodies of perched water. Of eight holes that penetrated the Bandelier, only hole 17.234 yielded perched water between the depths of 450 and 472 feet in lump pumice of the Guaje Member, the lower part of the Bandelier Tuff. Four springs emerge from perched zones in the Tshirege Member at high altitudes on the eastern slopes of the Sierra de los Valles. Two of these springs 20.5.26.113 and 26.311, flow about 25 and 40 gpm, respectively, and emerge from beds of pumice at the base of the Tshirege Member near the head of Guaje Canyon. Spring 19.5.25.333 flows about 90 gpm from fractures in welded tuff of the Tshirege Member in Water Canyon. Spring 25.111 flows about 4 gpm from fractures in welded tuff of the Tshirege Member.

PUYE CONGLOMERATE

The Puye Conglomerate for the most part is above the main water table, but in places it contains bodies of perched water. The lower part of the conglomerate probably is below the main water table at the site of hole 19.6.17.234 in Los Alamos Canyon.

Holes 19.6.13.344, 14.221, and 19.7.20.221 penetrated bodies of perched water in the Totavi Lentil at depths ranging from 600 to 800 feet. These holes were cased, equipped with small pumps, and used in pumping tests. The coefficient of transmissibility computed from pumping tests at hole 19.6.14.221, most productive well of the group, is about 5,000 gpd per ft. The Totavi Lentil is relatively free of silt at this site. Large quantities of water probably could not be pumped from the Totavi Lentil, however, because the perched water zones are relatively thin.

Two test holes penetrated bodies of perched water in the fanglomerate member of the Puye. Hole 19.7.20.221a penetrated a body of perched water between the depths of 212 and 215 feet in a bed of breccia and silt between two basalt flows in the fanglomerate. Pumping tests indicate that the permeability of the breccia and silt is low and that the water body is a lens. When this lens of water is relatively large and is receiving recharge from summer rains or snowmelt, hole 20.221a will yield 3 to 4 gpm for a month or two. In dry periods the lens of water is small, and the well will be dry in about an hour when pumped at the rate of 3 to 4 gpm. Hole 19.6.14.221a penetrated a body of perched water at a depth of 110 feet in conglomerate of the fanglomerate member. This hole yields about 5 gpm for 10 minutes before being pumped dry.

Spring 18.7.20.312 emerges from the Puye Conglomerate in Ancho Canyon, about three-fourths of a mile west of the Rio Grande. The spring discharges about 50 gpm from a zone of perched water in the Totavi Lentil.

The main water table probably was penetrated by hole 19.6.17.234 in Los Alamos Canyon at a depth of 1,200 feet, 10 feet above the base of the fanglomerate member. The Totavi Lentil, underlying a quartz latite flow which interfingers with the lowest part of the fanglomerate member, was penetrated between the depths of 1,480 and 1,490 feet, nearly 300 feet below the main water table. The hole was not tested for yield, but a saturated section of only 10 feet probably would not have a high rate of yield to wells.

BASALTIC ROCKS OF CHINO MESA

The basaltic rocks of Chino Mesa are above the main water table, and they do not discharge large quantities of perched water, even where they are breached by White Rock Canyon. One small spring, 19.7.22.131, emerging from the old alluvium in Los Alamos Canyon probably is fed largely from ground water moving through the basalt that crops out immediately to the west. Seeps and small springs along White Rock Canyon adjacent to the Rio Grande probably are fed by ground water moving through zones between the basalt flows exposed in the walls of the canyon. The spring flow disappears beneath a talus deposit to emerge adjacent to the stream course. The total flow of all the springs and seeps emerging from basalt in this canyon is small. The basaltic rocks of Chino Mesa are unimportant as aquifers in the Los Alamos area.

UNDIFFERENTIATED UNIT OF THE SANTA FE GROUP

OCCURRENCE OF WATER

Beds of silt and sand and thin beds of conglomerate compose the aquifer of the undifferentiated unit of the Santa Fe Group in the Los Alamos area. All these beds below the altitude of the Rio Grande are saturated. The upper zone of saturation slopes upward to the east and to the west from the Rio Grande and ground water feeds the river. The depth below land surface to the top of the zone of saturation becomes progressively greater westward in the Los Alamos area, because the top of the saturated zone slopes upward to the west more gently than the land surface. Along the western margin of the Pajarito Plateau the unsaturated upper part of the unit in places is as much as 500 feet thick.

Water-table conditions prevail in the undifferentiated unit near the margins of the Rio Grande valley, but artesian conditions prevail in the unit in much of the Los Alamos area.

The permeability of the materials comprising the undifferentiated unit of the Santa Fe Group is not uniform, and the more permeable beds that yield water readily to wells are imperfectly connected. As a result, the pressure head in the unit varies with vertical and lateral distances. In Guaje Canyon well 19.7.5.112 (G5), the pressure head in the beds at shallow depth is several feet higher than in those at greater depth. It is probable that movement of ground water in this area has a downward component. The reverse is true in wells closer to the Rio Grande. In wells 13.114 (L1), 14.222 (L2), and 14.221 (L3), the higher pressure heads are at depth, and water probably moves upward through the intervening beds of low permeability in this area.

The piezometric surface slopes downward toward the river. The piezometric surface along Guaje Canyon slopes eastward but is irregular in places. Between wells 19.7.5.231 (G4) and 5.112 (G5) in Guaje Canyon, the gradient of the piezometric surface is only 50 ft per mile and between wells 4.411 (G2) and 4.133 (G3) it is more than 100 ft per mile. Apparently a concealed fault is between wells 4.411 (G2) and 4.133 (G3). Several poorly exposed faults were observed west of Otowi bridge. The faults probably are the surface expressions of a fault zone that is more conspicuous in the subsurface. The slope of the piezometric surface averages about 70 ft per mile.

RECHARGE, MOVEMENT, AND DISCHARGE

The undifferentiated unit is recharged mainly by infiltration of precipitation and by seepage from streams along longitudinal strips adjacent to the boundaries of the Rio Grande depression. Ground water moves slowly from the boundaries of the depression through the various water-bearing beds toward natural discharge points along the Rio Grande.

A small amount of recharge to the undifferentiated unit in the Los Alamos area is by direct infiltration of precipitation on the steep slopes of the Sierra de los Valles and on the flat-lying interstream areas of the Pajarito Plateau. But most of the recharge is the seepage from small streams and rivulets on the lower slopes of the Sierra de los Valles and on the western part of the Pajarito Plateau. The flood runoff of such streams and rivulets rarely reaches the Rio Grande. The floodflows in some streams reach as far east as the central part of the Pajarito Plateau before they are depleted by seepage losses.

Some of the water that percolates downward through the mountain and plateau areas forms local bodies of perched water in the rocks overlying the undifferentiated unit of the Santa Fe Group. Most of the perched water slowly percolates downward to the main zone of saturation in the undifferentiated unit. Some of the perched water is discharged by springs from these overlying rocks in the mountain and plateau areas and along White Rock Canyon without reaching the undifferentiated unit of the Santa Fe Group.

Ground water from both sides of the Rio Grande contributes to the streamflow of the Rio Grande. Streamflow measurements in the Rio Grande in dry weather indicate that the river gains 500–600 gpm per mile in a 21-mile reach below Otowi bridge. This increase in flow is derived largely from ground-water discharge from the undifferentiated unit of the Santa Fe Group and, to a lesser extent, from other rocks that crop out along White Rock Canyon.

AQUIFER HYDRAULIC COEFFICIENTS

As water is withdrawn from the more permeable beds in the aquifer by wells and the head in these beds is lowered, ground water under greater head in less permeable beds leaks into the adjacent more permeable beds. The most permeable beds yield water to wells readily, and the least permeable beds are confining beds for the artesian system.

When Guaje Canyon was first being considered by the town of Los Alamos as a site for a well field, 35 samples of the various outcropping beds of the undifferentiated unit of the Santa Fe Group were tested for permeability. Of the samples, 18 were selected from 5 of the most permeable types of sediments; 7 were selected from 4 types of intermediate permeability; and 10 samples were selected from sedimentary rock of relatively low permeability.

The most permeable type was fine to coarse slightly silty pinkish-gray very poorly cemented sand that commonly is crossbedded. The coefficients of permeability of the 18 samples tested ranged from about

5 to 100 gpd per sq ft, and the median permeability was between 10 and 50 gpd per sq ft. This type of sand constitutes only a small proportion of the unit, possibly 5–10 percent.

Somewhat less permeable rocks is grayish-pink sandstone that is massive to thinly bedded and moderately well cemented. The seven samples from four different beds ranged in permeability from about 5 to 50 gpd per sq ft, and five of the seven samples ranged in permeability from 5 to 13 gpd per sq ft. Such rocks are estimated to constitute about 10–20 percent of the undifferentiated unit of the Santa Fe Group in the area.

Samples of the more common types of sedimentary rock—silt, very silty sand, and sandy silt—ranged in permeability from about 0.1 to 5 gpd per sq ft, although the median permeability was between 0.1 and 1 gpd per sq ft.

Only a small part of the sedimentary rocks are even moderately permeable. Therefore, a well tapping even a thick section of the undifferentiated unit of the Santa Fe Group in the Los Alamos area probably will not yield much more than 500 gpm.

PUMPING TESTS

Hydraulic characteristics of the aquifers and wells were determined, in part, from a series of pumping tests in the Los Alamos and Guaje Canyon well fields.

The first tests were made in the Los Alamos Canyon well field in 1950 and were analyzed and described by Theis and Conover (1960). Well 19.7.14.221 (L3), which is 870 feet deep, was pumped steadily for 2 weeks and the resultant water-level fluctuations were observed in nearby wells. Theis and Conover concluded that the coefficient of transmissibility for the upper 1,000 feet of the undifferentiated unit of the Santa Fe Group in the vicinity of the Los Alamos Canyon well field is about 2,500 gpd per foot. The values computed by them for the coefficient of storage ranged from 0.0033 to 0.0035.

The results of a brief test in well 15.434 (L5), which is 1,750 feet deep, indicated a coefficient of transmissibility of about 6,500 gpd per foot. This well tapped aquifers below those tapped by well 14.221 (L3); thus, it was concluded that the coefficient of transmissibility of the upper 2,000 feet of the undifferentiated unit is the sum of the coefficients of these two tests, or about 9,000 gpd per ft.

The author ran pumping tests at all of the Guaje Canyon supply wells prior to 1955. The plan of the Guaje Canyon well field is shown in figure 20. Well 19.7.4.133 (G3) was pumped at a constant rate for 8 days when tested, but each of the other wells was pumped for only 48 hours. The specific capacities of the five wells ranged from

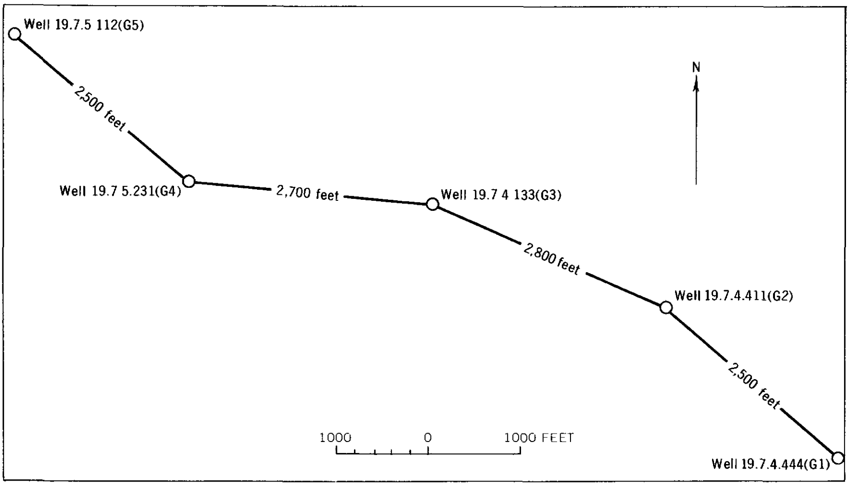

FIGURE 20.—Sketch showing the plan of the Guaje Canyon well field near Los Alamos, N. Mex.

about 5 to 7 gpm per ft of drawdown. Coefficients of transmissibility ranged from 7,500 gpd per ft at well 4.133 (G3) to 16,000 gpd per ft at well 4.444 (G1), and were 10,000, 11,000, and 12,000 gpd per ft respectively at wells 4.411 (G2), 5.112 (G5), and 5.231 (G4). The low coefficient of transmissibility computed using data from well 4.133 (G3) probably reflects a hydraulic boundary in the aquifer, possibly a buried fault between wells 4.133 (G3) and 4.411 (G2). The coefficient of transmissibility computed using data from well 4.444 (G1) may be too high because the data could not be corrected to account for the incomplete recovery of water level in the well before the pumping test was started. Coefficients of transmissibility that ranged from 10,000 to 12,000 gpd per ft may approximate the actual coefficient of the water-bearing beds between the top and bottom of the screened section of the wells. These beds have a total thickness of about 400 feet.

Later a 13-day continuous discharge pumping test was made by the author using wells 19.7.4.444 (G1) and 5.112 (G5) as the pumped wells. The discharge of well 4.444 (G1) ranged between 520 and 535 gpm and averaged 525 gpm; that of well 5.112 (G5) ranged between 535 and 545 gpm and averaged about 540 gpm. Conditions for this test were better than those of previous tests.

The water level of well 4.444 (G1) declined 108 feet during the pumping period, indicating a specific capacity of 4.8 gpm per ft of drawdown; that of well 5.112 (G5) declined 99 feet, indicating a specific capacity of 5.4 gpm per ft of drawdown. The water levels in the nonpumped supply wells 4.411 (G2), 4.133 (G3), and 5.231 (G4) declined 13.2 feet, 5.2 feet, and 11.6 feet, respectively. The water-level declines in these nonpumped wells reflected the cumulative pressure reduction in the aquifer at those wells caused by pumping wells 4.444 (G1) and 5.112 (G5). Most if not all the water-level decline in well 4.411 (G2) is attributable to the pressure reduction in the aquifer from pumping of well 4.444 (G1); similarly, pumping of well 5.112 (G5) probably caused most of the water-level decline in well 5.231 (G4). Well 4.133 (G3) is equidistant from the two pumped wells, and theoretically a half of the water-level decline in well 4.133 (G3) is attributable to each of the pumped wells. The pumped wells probably did not exert equal effects on the water level in well 4.133 (G3) because a fault between wells 4.133 (G3) and 4.411 (G2) may have retarded and diminished the spread of the pressure reduction in the aquifer betwen pumped well 4.444 (G1) and well 4.133 (G3) and increased the pressure reduction in the aquifer at well 4.133 (G3) as the result of pumping well 5.112 (G5). The data were inconclusive with respect to this problem.

The water-level declines of 13.2 feet and 11.6 feet respectively in wells 4.411 (G2) and 5.231 (G4) are large considering the relatively large distance (2,500 ft) the wells are from the pumped wells. The magnitude of the declines at a distance of 2,500 feet, however, is not uncommon in an artesian system similar to that in the undifferentiated unit of the Santa Fe Group. Wells in this aquifer should be spaced sufficiently far apart to minimize pressure-reduction interference among wells.

The coefficients of transmissibility and storage computed from data obtained during the 13-day pumping test are shown below. These computed coefficients of transmissibility ranged from 7,700 gpd per ft to 25,000 gpd per ft. The low coefficient of transmissibility computed using data from well 5.112 (G5) probably reflects a hydraulic boundary, but an analysis was not made to determine the position and nature of the boundary. The average of the coefficients of transmissibility given is 15,000 gpd per ft. The coefficients of transmissibility computed from the various tests are for that part of the aquifer tapped by the wells; and the coefficients determined from wells G4 and G5 are doubtful because of unanalyzed boundary conditions.

The coefficients of storage, calculated only from the drawdown of water levels in wells 4.411 (G2) and 5.231 (G4) were 0.0002 and 0.0004, respectively. The actual coefficient of storage of a leaky artesian aquifer, however, changes with time, and leakage of water from and through relatively impermeable confining beds contributes to the quantity of water that the undifferentiated unit of the Santa Fe Group will yield to wells over a long time.

Method		Coefficient of transmissibility (gpd per ft)	Coefficient of storage
Drawdown in well	19.7.4.444(G1)	11, 700	------------
	4.411(G2)	15, 000	0. 0002
	5.231(G4)	17, 500	. 0004
	5.112(G5)	7, 700	------------
Recovery of well	4.444(G1)	14, 700	------------
	4.411(G2)	16, 500	------------
	5.231(G4)	25, 000	------------
	5.112(G5)	12, 000	------------

Some drawdown and recovery of water levels during the 13-day test when plotted against the logarithm of the test time have anomalous features, which are interpreted as indicating interformational leakage. A line drawn through the plotted data points for wells 19.7.4.411 (G2), 4.444 (G1), and 5.112 (G5) for the first 10 hours of pumping, form a curve. The line for the period from 10 hours to about 100 hours approximates a straight line. 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 continues to decrease. The change in slope of the plotted line reflects the leakage of water from or through the relatively impermeable confining beds. Coefficients of storage computed from the changing slopes of the line after 100 hours show progressively higher values for the undifferentiated unit of the Santa Fe Group as the length of the pumping period increases.

WATER-LEVEL CHANGES CAUSED BY PUMPING

In general, water levels in the undifferentiated unit in the Los Alamos area will decline with respect to the rate of withdrawal, and for any rate of withdrawal the decline will vary with the logarithm of the length of the withdrawal period. In places the decline of the water level will be accelerated because of nearby boundaries that restrict the movement of water in the aquifer.

The piezometric surface in the Los Alamos Canyon well field declined about 35 feet after about 2 years (1948–49) of pumping at an average rate of about 500 gpm and declined an additional 25–30 feet after 3 more years (1950–52) of pumping at about 1,000 gpm. Assuming that pumping will continue at an average rate of 1,000 gpm, Theis and Conover (1960) computed that the total decline of water level in the Los Alamos Canyon well field will be 125 feet by 1975. Withdrawal from the Guaje Canyon well field eventually will contribute to the decline of water levels in the Los Alamos field. The time when the effect of pumping from the Guaje Canyon wells will reach the Los Alamos Canyon field cannot be predicted because leakage from less permeable to more permeable beds will retard the expansion of the cones of depression. This leakage will moderate the lowering, with the result that the lowering of water levels in the Los Alamos Canyon well field probably will be appreciably less than that computed by Theis and Conover.

Large-scale pumping began in the Guaje Canyon field in 1952 and the pumping rate averaged 670 gpm for the year. The nonpumping water level declined 15–20 feet during the year. Assuming that in 1953 and succeeding years the rate of withdrawal increases to about 1,000 gpm, and there will be no water-level interference from the Los Alamos field, the levels probably would decline a total of about 50 feet by 1975. The effect of pumping in the Los Alamos field, however, will eventually reach the Guaje wells, and will cause additional drawdowns in the Guaje wells. 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 estimated amount of decline may be excessive because leakage to the aquifer probably will retard the decline of water levels. The above estimates of lowering of water levels are given only to indicate the magnitude to be expected.

CHEMICAL QUALITY OF WATER

Samples of water were collected from time to time from each of the Los Alamos wells in Los Alamos and Guaje Canyons and the water analyzed for its chemical constituents. The analyses of these samples are given in table 4. An analysis of water from well 19.7.36.314 at Buckman is included in the table.

Water from the Los Alamos Canyon well field contains low to moderate concentrations of dissolved solids. Most of the wells yield water having less than 250 ppm of dissolved solids, and all wells yield water having less than 50 ppm equivalent $CaCO_3$ (hardness). Silica content generally ranged between 30 and 40 ppm, which is not as high as that in water from most other wells in the region. Fluoride content in water from well 14.312 (L6) is more than 2.0 ppm at times. It is less than 1.5 ppm in all other wells in the Los Alamos Canyon and is less than 1.0 ppm in most. The westernmost well in this group, well 22.114 (L4) yields water of the best quality. The predominant mineral constituents of the water from this well field are sodium and bicarbonate. Except for the fluoride of well 14.312 (L6), the mineral constituents of water from this well field are within acceptable limits for domestic and most other uses.

Quality of water from several of the wells in the Los Alamos Canyon field changed slowly with time. In order to study these changes, three of the wells were sampled several times during the investigation. Except for well 19.7.14.312 (L6), water from those wells which were sampled more than once changed little in quality during the period of record. Most of the changes observed thus far are minor, and no definite pattern of fluctuation is apparent.

Water from the Buckman well 36.314 is similar in quality to that from the Los Alamos Canyon wells.

Analyses of samples of water from the Guaje Canyon wells are included in table 4. Water from the wells in this field has a narrower range of dissolved solids concentration than the water from the wells in Los Alamos Canyon, but the average for both fields is nearly the same. The westernmost well, 5.112 (G5), yields water with the least amount of dissolved solids in this field, but this water is of the calcium bicarbonate type and is moderately hard. Wells east of well 5.112 (G5) in Guaje Canyon yield softer water but water that is somewhat higher in dissolved solids. The silica content of the Guaje Canyon waters is comparatively high, especially that from well 4.444 (G1), where one sample had 88 ppm. The silica content of the water from this well has increased notably since the well was first put in use. Except for well 4.444 (G1), the dissolved-solids content of water from this field has decreased since 1951.

SUMMARY OF GROUND-WATER RESOURCES

VALLES CALDERA AREA

The volcanic rocks of the caldera area will not yield water to wells in quantities sufficient for the requirements of Los Alamos. In general, the volcanic rocks are above the main water table; but, locally, perched bodies of water in these rocks will yield small quantities to wells. The blocky crust of the rhyolite domes are excellent recharge areas, and water entering these rocks discharges into the caldera fill.

The sedimentary rocks of the caldera fill are the principal aquifers of the caldera area. The fill in Valle Toledo and Valle Grande contains several thousand acre-feet of ground water in storage, most of which is artesian. Water will flow from deep wells constructed in the valley lowlands. The specific capacities of large-diameter deep wells probably will exceed 10 gpm per foot of drawdown.

The perennial flow in San Antonio Creek in Valle Toledo and East Fork of Jemez River in Valle Grande is fed by springs. Withdrawal of ground water in sufficient quantities from these valleys would decrease the spring discharge and consequently the streamflow. These surface waters are fully appropriated; therefore, withdrawal of water by wells in the caldera area would interfere with established surface-water rights.

RIO GRANDE AREA

Perched bodies of ground water are contained in some rocks above the main water table, but these bodies are small and yield water slowly to wells. These perched bodies are not a reliable source of water to wells, but they maintain the flow of a few small springs.

The Tschicoma Formation contains small bodies of perched water some of which discharge as springs on the eastern slope of the Sierra de los Valles. Deep test holes penetrated rocks of the Tschicoma Formation below the main water table, but pumping tests indicated that the permeability of these rocks was very low. In general, the Tschicoma Formation is a poor aquifer.

The Bandelier Tuff is above the main water table but contains local bodies of perched water. Some of the larger springs in the eastern slope area issue from the Tshirege Member of the Bandelier Tuff. The Bandelier Tuff is a poor source of water for wells, however.

The Puye Conglomerate for the most part is above the water table but contains local bodies of perched water. The lower part of the Puye probably is below the main water table in places, but the saturated section generally is only a few feet thick and is therefore not an important aquifer in the area.

The basaltic rocks of Chino Mesa are above the main water table and contain only local bodies of perched water. These rocks are unimportant as aquifers in the Los Alamos area.

The undifferentiated unit of the Santa Fe Group contains the principal aquifers in the Los Alamos area. In most of the area the water in the undifferentiated unit is under artesian pressure. In the lowlands along the Rio Grande and at altitudes below about 5,700 feet in tributary canyons west of the Rio Grande, the artesian pressure is sufficiently great to cause water to flow from properly constructed deep wells. Wells constructed similarly to those of the Los Alamos and Guaje Canyon well fields and penetrating 800 or more feet below the piezometric surface in the undifferentiated unit probably will have a specific capacity between 3 and 7 gpm per foot of drawdown.

The maximum thickness of the undifferentiated unit in the Los Alamos area is not known, but test drilling has shown that its thickness is in excess of 2,000 feet. The permeability of the water-bearing material comprising the aquifers in this unit is not uniform, and the combined thickness of the aquifers within the first 2,000 feet are not equal throughout the Los Alamos area. The coefficient of transmissibility of this 2,000-foot section probably is 10,000–12,000 gpd per ft or more. Some fault zones form partial barriers to the movement of ground water in the unit. Wells near such a barrier will have a lower specific capacity and a larger decline in water level when pumped.

In the artesian system of the undifferentiated unit the pressure relief caused by a discharging artesian well reaches hundreds of feet from the well in a relatively short period of time. If wells are too closely spaced, the pressure relief in the aquifer caused by the discharge of each well would adversely affect the water level in all wells within the area of pressure disturbance. This interference among wells will result in a decrease in discharge or an increase in pumping lift for all wells affected. Proper spacing of wells and scheduling of pumping times would minimize the interference among wells in a well field.

REFERENCES

Bryan, Kirk, 1938, Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico, *in* [U.S.] Natl. Resources, Regional Resources Planning Board, The Rio Grande joint investigation in the upper Rio Grande basin, 1936–37: Washington, U.S. Govt. Printing Office, v. 1, pt. 2, p. 197–225.

Cabot, E. C., 1938, Fault border of the Sangre de Cristo Mountains north of Santa Fe, New Mexico: Jour. Geology, v. 46, no. 1, p. 88–105.

[California] State Water Pollution Control Board, 1952, Water quality criteria; pub. no. 3, 512 p., addendum no. 1, 164 p. [1954]; 2d printing (including addendum no. 1) 1957,: p. 257.

Cope, E. D., 1877, The extinct vertebrata obtained in New Mexico by parties of the expedition of 1874 *in* Wheeler, G. M., 1877, Annual report upon the geographical surveys west of the 100th Meridian in the states and territories of California, Oregon, Nevada, Texas, Arizona, Colorado, Idaho, Montana, New Mexico, Utah, and Wyoming: Washington, U.S. Govt. Printing Office, no. 4, pt. 2, 371 p.

Darton, N. H., 1928, Geologic map of New Mexico: U.S. Geol. Survey, scale 1:500,000.

Denny, C. S., 1940, Santa Fe formation in the Espanola Valley, New Mexico: Geol. Soc. America Bull., v. 51, no. 5, p. 677–694, 4 pls., 2 figs.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.

Fitzsimmons, J. P., Armstrong, A. K., and Gordon, MacKenzie, Jr., 1956, Arroyo Penasco formation, Mississippian, north-central New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 8, p. 1935–1944.

Frick, Childs, 1933, New remains of Trilophodont—Tetrabelodont Mastodons: Amer. Mus. Nat. History Bull., v. 59, art. 9, p. 505–562, 2 pls., 36 figs.

——— 1937, Horned ruminants of North America: Amer. Mus. Nat. History Bull., v. 69, 669 p., 103 figs.

Hayden, F. V., 1873, First, second, and third annual reports of the U.S. Geological Survey of the Territories for the years 1867, 1868, and 1869 [repr.]. Washington, U.S. Govt. Printing Office, 261 p. [1873].

Hewitt, E. L., 1953, The Pajarito Plateau and its ancient people: Albuquerque, Univ. of New Mexico Press, 174 p.

Iddings, J. P., 1890, A group of volcanic rocks from the Tewan Mountains, New Mexico: U.S. Geol. Survey Bull. 66, 34 p.

Johnson, D. W., 1904, Geology of Cerrillos Hills, New Mexico: New Era Printing Co., Lancaster, Pa., 204 p.

Kelley, V. C., 1954, Tectonic map of a part of the upper Rio Grande area, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map OM 157.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., 1910, The ore deposits of New Mexico: U.S. Geol. Survey Prof. Paper 68, 361 p.

Osborn, H. F., 1909, Cenozoic mammal horizons of western North America, with faunal lists of the Tertiary mammalia of the west, by W. D. Matthew: U.S. Geol. Survey Bull. 361, 138 p., 3 pls.

——— 1918, Equidae of Oligocene, Miocene, and Pliocene of North America, iconographic type revision: Am. Mus. Nat. History Mem., N. S., v. 2, pt. 1, p. 1–330.

Paulsen, C. G., 1951, Surface water supply of the United States, pt. 8. Western Gulf of Mexico basins: U.S. Geol. Survey Water-Supply Paper 1212, 383 p., [1953].

Smith, H. T. U., 1938, Tertiary geology of the Abiquiu quadrangle, New Mexico: Jour. Geology, v. 46, no. 7, p. 933–965, 12 figs.

Spiegel, Z. E., and others, 1958, Geology and water resources of the Santa Fe area, New Mexico, pt. 2, Geology: U.S. Geol. Survey open-file rept., p. 42–150.

Theis, C. V., and Conover, C. S., 1960, Pumping tests in Los Alamos Canyon well field near Los Alamos, New Mexico: U.S. Geol. Survey open-file rept., 40 p., 10 figs.

Theis, C. V., Conover, C. S., and Griggs, R. L., 1960, Preliminary report on the geology and hydrology of Valle Grande and Valle Toledo, Sandoval County, New Mexico: U.S. Geol. Survey open-file rept., 65 p., 14 figs.

Wood, G. H., and Northrop, S. A., 1946, Geology of Nacimiento Mountains, San Pedro Mountains, and adjacent plateaus in parts of Sandoval and Rio Arriba counties, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 57 [compilation by Marion Jo Cowan].

Wood, H. E., 2nd, Chaney, R. W., Clark, John, Colbert, E. H., Jepson, G. L., Reeside, J. B., Jr., and Stock, Chester, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America, Bull., v. 52, no. 1, p. 1–48, 1 pl.

INDEX

[Italic numbers indicate principal references]

U.S. GOVERNMENT PRINTING OFFICE : 1964 O—722-218

The U.S. Geological Survey Library has cataloged this publication as follows:

Griggs, Roy Lee, 1914–
Geology and ground-water resources of the Los Alamos area, New Mexico. With a section on quality of water, by John D. Hem. Washington, U.S. Govt. Print. Off., 1964.

v, 106 p. illus., maps (1 fold. col. in pocket) diagrs., tables. 24 cm. (U.S. Geological Survey. Water-supply paper 1753)
Prepared in cooperation with the U.S. Atomic Energy Commission.
Bibliography: p. 103–104.

(Continued on next card)

Griggs, Roy Lee, 1914– Geology and ground-water resources of the Los Alamos area, New Mexico. 1964. (Card 2)

1. Geology—New Mexico—Los Alamos region. 2. Water-supply—New Mexico—Los Alamos region. 3. Water, Underground—New Mexico—Los Alamos region. 4. Borings—New Mexico—Los Alamos region. 5. Water—Analysis. I. Hem, John David, 1916– II. Title: The Los Alamos area, New Mexico. (Series)