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by

William D. Purtymun

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ABSTRACT

The Jemez Plateau at the site proposed for a geothermal-energy study forms an apron around the west side of the Valles Caldera. Five test holes were drilled on the plateau for geologic information, temperature data, and to investigate drilling problems. Four of the test holes, ranging in depth from 500 to 750 ft, penetrated volcanic rocks of Cenozoic Age and were completed into the sediments of Permian Age. A deep test hole, drilled 2575 ft, penetrated the volcanic rocks of Cenozoic Age and sediments of Permian and Pennsylvanian Age, and is completed into the rocks of Precambrian Age. The basic part of the study is to be made in the Precambrian rocks. Test drilling and measured sections indicate a small north-south trending basin near the center plateau in which the sediments thicken. The basin may be structural in part or erosional where the upper surface of Precambrian rocks was cut to form a small valley before deposition of the sediments. The geologic logs of the five test holes are included.

I. INTRODUCTION

The site tentatively selected for the first major geothermal-energy study proposed by the Los Alamos Scientific Laboratory is on the Jemez Plateau, about 20 miles west of Los Alamos, New Mexico (Fig. 1). It was chosen principally on the basis of preliminary geologic investigations and geothermal-gradient measurements made in a series of shallow test holes drilled in the region of the Valles Caldera. These indicated that in the area west of the caldera, the geology and geologic structure were least complicated. Also, competent rock (Precambrian basement) at temperatures needed for the experiment could be reached easily by conventional drilling methods (at depths varying from 8000 to 10,000 ft).

Four test holes ranging in depth from 500 to 750 ft were drilled in this area during April 1972. They were cored and cased for geologic investigations and heat-flow measurements. A deeper test hole was drilled during May and June 1972 to obtain additional geologic information and temperature data and to investigate drilling problems in the area. It reached a depth of 2575 ft and was completed in the Precambrian basement rocks.

This report describes the geology and geologic structure of the proposed experimental site on the basis of data obtained from test drilling in the area during April through June 1972. These data are supplemented by the results of other investigations made in the area, including those made by the authors, listed below.

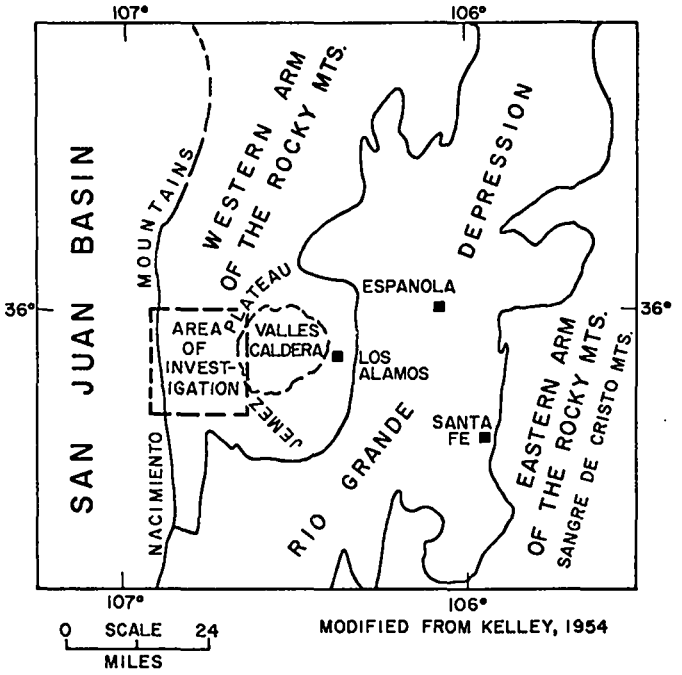

Fig. 1. Major structural features and area of investigation in north-central New Mexico.

The geology of this region was first described by Renich,[1] and has since been described by Woods and Northrop,[2] Smith et al.,[3] Ross et al.,[4] and Bailey et al.[5] A regional geologic map was published by Smith et al.[6] Fitzsimmons[7] describes some of the Precambrian rocks in the area, and Doell et al.[8] present data on the age-dating and paleomagnetism of the volcanic rocks in the Jemez region.

II. GEOGRAPHY

The proposed experimental site is located on the Jemez Plateau, which is a part of the western arm of the Rocky Mountains that extends into northern New Mexico from southern Colorado. The surface of the plateau is formed by volcanic ash extruded during the volcanic activity that produced the Valles Caldera.

The caldera is surrounded by mountains formed during this same period of active volcanism. The volcanic ash forms an apron around the caldera, which laps onto the flanks of these mountains. The Jemez Plateau is the western part of this apron (Fig. 1). The north-south-trending Nacimiento Mountains form the western boundary of the area of investigation.

The altitudes of mountains bounding the Jemez Plateau on the east and west range from about 10,000 ft at the westernmost dome in the caldera (San Antonio Mountain) to a little over 9000 ft along the crest of the Nacimiento Mountains. The major drainage in the area is the Rio de Las Vacas and Jemez Creek, with its tributary, San Antonio Creek (Fig. 2). The proposed experimental site is on the plateau between the Rio de Las Vacas and San Antonio Creek. A high ridge along the western part of the plateau is parallel to San Antonio Creek. Otherwise the surface of the plateau slopes gently downward to the west and southwest. The altitude of the area ranges from 8000 to 9000 ft along the crest of the ridge to about 7000 to 8000 ft where the plateau terminates in steep slopes or cliffs above the Rio de Las Vacas. The plateau surface is cut into a number of mesas by southwest-trending streams

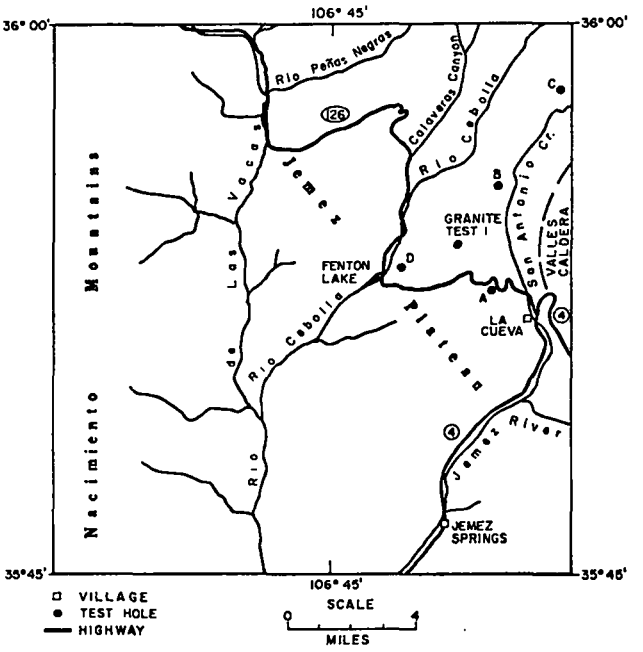

Fig. 2. Cultural and drainage features and locations of test holes in the area of investigation.

that are tributary to the Rio de Las Vacas, the largest of which is the Rio Cebolla.

West of the Rio de Las Vacas the eastern flanks of the Nacimientos rise gently to the crest and then break abruptly in a steep slope into the San Juan Basin.

The average annual precipitation in the area is estimated to range from about 14 in. at lower elevations to about 22 in. in the mountains. Average annual air temperatures range from 40 to 50°F (Ref. 9).

The high mountain slopes are forested mainly with ponderosa pine and some fir and spruce. Groves of aspen and live oak are found in the higher canyons, with some willow and poplar along the streams at the lower elevations. About 5000 acres of the forest, west of La Cueva and south of State Road 126, were burned in a forest fire in 1971.

Access to the area from Los Alamos is on State Highway 4 to La Cueva and State Road 126 northwest to Fenton Lake and Cuba. Logging and service roads off State Road 126 provide additional access to the Jemez Plateau.

III. GEOLOGY

The area of investigation is a part of the southern extension of the Rocky Mountains that lies between the structural features of the San Juan Basin to the west and the Rio Grande Depression to the east (Fig. 1). Precambrian, Pennsylvanian, Permian, Mesozoic, and Cenozoic rocks outcrop in the area (Fig. 3).

IV. STRATIGRAPHY

Precambrian rocks of granite and gneiss outcrop along the flanks and crest of the Nacimiento Mountains. These are overlain by Pennsylvanian and Permian limestones, sandstones, and shales. Mesozoic sediments outcrop in the northwest part of the area and on the western slopes of the Nacimiento Mountains, but because they do not extend beneath the Jemez Plateau they are not further considered in this report. The Cenozoic volcanic rocks form the upper surface of the Jemez Plateau, overlying the Permian, Pennsylvanian, and Precambrian rocks.

V. PRECAMBRIAN ROCKS

The Precambrian rocks are particularly important to the proposed geothermal-energy experiment because it is intended that they will contain the pressurized-water circulation system.

Granite is the most abundant type of Precambrian rock. This granite is coarse-grained with large insets of microcline. Microcline is the dominant feldspar, although albite-oligoclase is usually also present in smaller amounts. Quartz is abundant, with biotite a common mafic mineral.

Quartz-feldspar gneiss is common. The feldspar consists mainly of microcline. However, oligoclase-andesine is also abundant, although it is finer-grained and more uniformly spread throughout the rocks. The quartz shows moderate straining. Accessory minerals are hornblende, biotite, and epidote, and some sphene, apatite, zircon, and magnetite. Granite Test 1 penetrated augen-gneiss in which the augen ("eyes") were of microcline (Table I). The gneiss is lenticular, with planes of foliation. The foliation has a general, characteristic northeast trend, which has also been observed to the southeast in the Sandia, Manzanito, and Manzano Mountains--as if deformation and metamorphism had taken place in a single major event with forces acting at right angles to the foliation (Ref. 7).

Associated in a few places with the granite is a black intrusive rock, mostly in dikes. Also cutting the granite in many places are quartz veins, most of which are less than 6 in. in width (Ref. 1). Granite Test 1 penetrated a dark gray amphibolite consisting mainly of amphibole and plagioclase. A few small outcrops occur in the Precambrian along the Rio de Las Vacas.

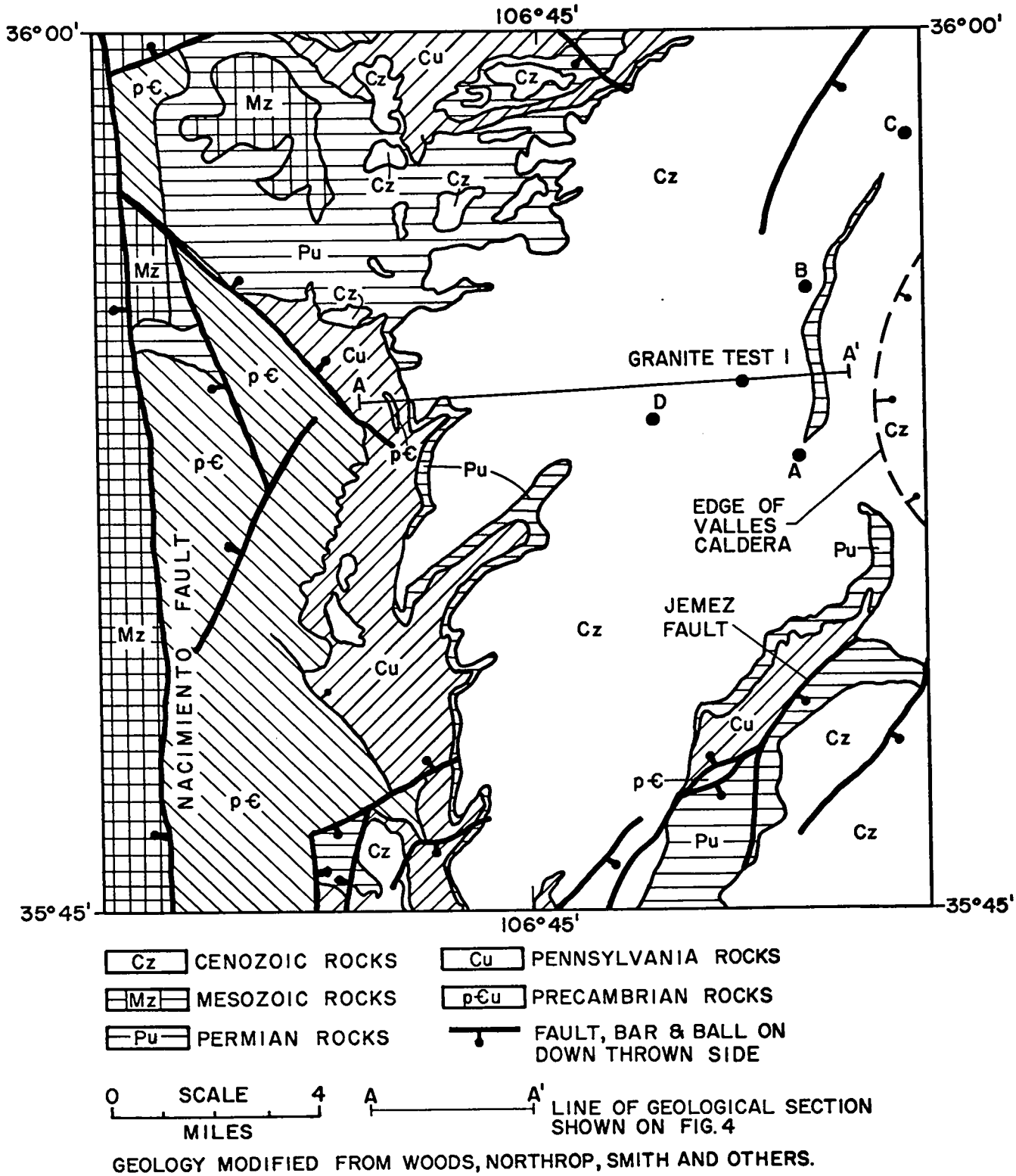

Fig. 3. Generalized geologic map of the area of investigation.

There are no apparent outcrops of pegmatites or greenstone schists, although there are a few outcrops of mica schist into which the granites have been intruded.

The color of the granites ranges from brownish gray to red, whereas the predominant color of the gneiss ranges from pinkish gray to red. The granites weather to spheroidal boulders and hummocks. The gneiss weathers to rounded knolls and undulating uplands.

VI. PENNSYLVANIAN ROCKS

The Pennsylvanian rocks are dominantly massive limestones, shales, and arkose. In the area of investigation these rocks comprise the Magdalena Group, which includes the lower Sandia formation and overlying Madera limestone. Although these strata are combined on the map (Fig. 3), the cross section (Fig. 4) in the area of the experimental site shows individual units within the two formations.

The Sandia Formation is divided into the lower limestone member and the upper clastic member. The lower limestone member is a dark gray, siliceous limestone, whereas the overlying clastic member consists of dark brown to brownish-green sandstone and arenoceous shale and limestone. The lower limestone member is discontinuous, so that in some areas the upper clastic member rests on the Precambrian rocks (Ref. 2). Both clastic member and lower limestone member were present in Granite Test 1 (Table I).

The Madera limestone is composed of a lower, gray limestone member and an upper arkosic limestone member. The lower gray limestone consists of a dark gray limestone interbedded with gray shale and a few sandstone beds. The upper arkosic limestone member is of limestone and arkosic limestone, alternating with gray and red arkosic shale.

The thickness of the Pennsylvanian rocks of the Magdalena Group varies, and in some places

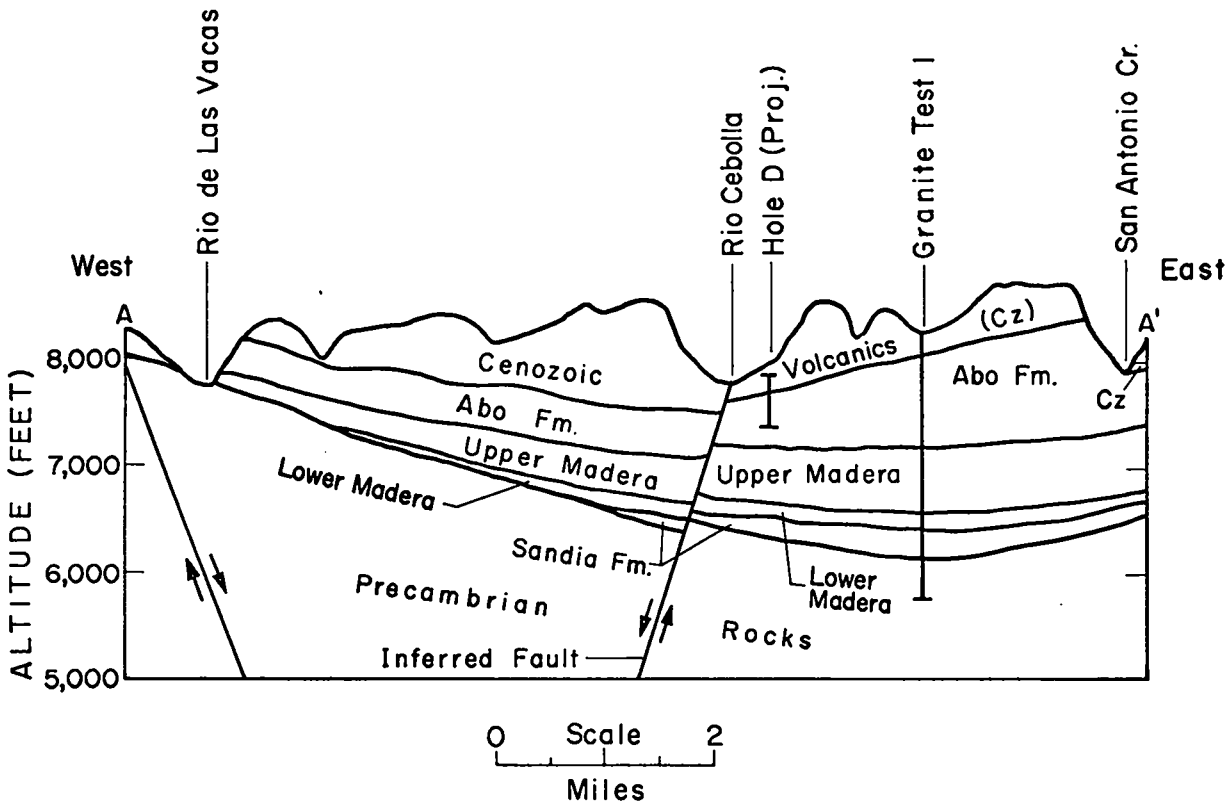

Fig. 4. Geologic section from the Rio de Las Vacas to San Antonio Creek.

they are not present--either because they were removed by erosion before deposition of the overlying Permian rocks or because they were never deposited. Shown below are the thicknesses of sections measured elsewhere and the thicknesses penetrated by Granite Test 1.

Location Reference	Section Thickness in Feet 1	2	3	4	5
Madera Limestone					
Arkosic limestone	610	230	340	410	590
Gray limestone	120	200	-	-	155
Sandia Formation					
Upper clastic	200	210	-	-	235
Lower limestones	30	30	-	-	55

1. Rio de Las Vacas, 5 miles southwest of Jemez Springs.
2. Jemez Creek, near Jemez Springs.
3. Rio de Las Vacas, 5 miles west of Fenton Lake.
4. Ten miles northwest of Fenton Lake.
5. Granite Test No. 1, LASL.

Sections 1, 2, 3, and 4 were measured in the field (Ref. 2) and rest directly on the Precambrian rocks. Section 5, Granite Test 1, did penetrate into the Precambrian rocks.

VII. PERMIAN ROCKS

The Permian rocks were deposited on an old flood plain that may have been flooded periodically by marine waters, although the irregular bedding in the sandstones suggests a fluvial mode of deposition for most of the rocks, in a continental environment.

In the area of investigation the Permian rocks are of the Abo Formation. The formation consists of arkosic siltstone, sandstone, and shale. The sandstone is fine-grained with occasional lenses of pebbly conglomerate. Lenses of clay also occur, as well as some minor and thin lenses of arkosic limestone. The formation is made up of alternating layers of shale, siltstone, sandstone, and clay, with the shales making up the larger part of the section. Quartz grains are numerous in coarser-bedded material; however, some feldspar is also present, as well as small particles of igneous rock. The Abo in the lower part of the section may contain some reworked material from the Magdalena Group. The color of the formation is predominantly various shades of red, from light to very dark. There are some calcareous lenses that range in color from white to dark gray.

The upper surface of the Abo was heavily eroded prior to the deposition of the Cenozoic volcanics. Thus the thickness of the Abo varies, due to this irregular surface. Various thicknesses in the area are presented in the following table. Test Hole A (Table II), Test Hole B (Table III), Test Hole C (Table IV), and Test Hole D (Table V) did not penetrate the complete section of the Abo but are completed 335, 210, 170, and 380 ft, respectively, into the upper part of the formation.

Location Reference	Section Thickness in Feet 1	3	5
Abo Formation	590	700	910

VIII. CENOZOIC ROCK

The Cenozoic rocks are made up of volcanics or sediments derived from volcanic rocks. The older Cenozoic rocks--the Abiquiu Tuff and the Tschicoma Formation--are exposed in the west wall of the canyon cut by San Antonio Creek north of La Cueva, whereas the younger rocks--the Bandelier Tuff--form the upper part and surface of the Jemez Plateau (Fig. 3).

The Abiquiu Tuff lies in the topographically low areas in the eroded surface of the Abo Formation. It is composed mainly of white to light gray tuffaceous sandstone and conglomerate, which includes a basal gravel member that includes pebbles and sand derived from the Precambrian crystalline rocks. Test Hole A (Table II), Test Hole C (Table IV), and Granite Test 1 penetrated the Abiquiu Tuff at 125, 340, and 100 ft, respectively.

The Tschicoma Formation overlies the Abo Formation and a part of the Abiquiu Tuff along the west wall of the canyon cut by San Antonio Creek. The formation is a thin pyroclastic flow of dark gray latite that, in places, contains some thin lenses of light gray clay. The formation contains phenocrysts of plagioclase and some smaller crystals of quartz, biotite, hornblende, and augite, in a fine grained gray matrix. Test Hole B (Table III) penetrated about 60 ft of the Tschicoma above the Abo Formation.

The Bandelier Tuff forms the upper part and the surface of the Jemez Plateau overlying the older volcanic rocks of the Tschicoma Formation--Abiquiu Tuff and, in places, the sediments of the Abo Formation. The Bandelier Tuff ranges from a nonwelded to a welded rhyolite tuff, with colors from light gray to dark gray. The tuff is made up of crystals and crystal fragments of quartz and sanidine, glass shards, and some mafic minerals as well as rock fragments, pumice, latite, and rhyolite in a fine-grained ash matrix. The Bandelier Tuff thins to the west and southwest away from the source area, the Valles Caldera. Test Holes A, B, C, and D, and Granite Test 1 penetrated thicknesses ranging from 30 to 380 ft of the Bandelier Tuff (Tables I through V).

The ages of the volcanic rocks in the area of investigation and in adjacent areas were determined by potassium-argon methods (Refs. 5 and 8). The ages presented here are not for correlation of geologic formations but to show the time span of volcanic activity in the Valles Caldera Region. The Abiquiu Tuff is associated with older volcanic centers to the north. It is much older than rocks in the Valles Region, ranging in age from 25 to 35 million years.

The ages of the El Cajete member and the Blanca Bonita member are estimated older than 42,000 years before present (BP), and younger than 0.1 millions of years (MY). Thus, in the area of investigation, the youngest to oldest volcanic rocks are the Bandelier Tuff (1.1 to 1.4 MY) and Tschicoma Formation (3.7 to 6.7 MY). However, in the Valles Caldera the intracaldera domes range from 0.4 to 1.0 MY, with the oldest volcanic activity associated with the Valles Caldera beginning about 9 million years ago. The westernmost intracaldera dome (San Antonio Mountain) adjacent to the site on the plateau has an age of 0.5 MY.

Volcanic Rocks (Unit Name)	K-Ar Age (Millions of Years)
Canvoas Canyon Rhyolite	8.5 to 9.1
Plaza Canyon Formation	8.5 to 9.1
Labato Basalt	7.4
Tschicoma Formation	3.7 to 6.7
El Rechuelos Rhyolite	2.0
Bandelier Tuff	
Upper Member	1.1
Lower Member	1.4
Valle Grande Member	
Intracaldera Domes	0.4 to 1.0
Battleship Rock Member	0.5

IX. STRUCTURE

The area of investigation is in the western arm of the Rocky Mountains between the Rio Grande Depression on the east and the San Juan Basin on the west (Fig. 1). The San Juan Basin, a part of the Colorado Plateau, is a large structural basin that extends from the western edge of the north-south-trending Nacimiento Mountains into northwestern New Mexico. The deepest part of the basin contains over 18,000 ft of Mesozoic and Cenozoic sediments. The Rio Grande Depression to the east is a structural depression that extends from southern Colorado through central New Mexico into northern Mexico (Ref. 10). Near Los Alamos, the depression, formed by north-south-trending faults, contains over 12,000 ft of sediments above the Precambrian rocks (Ref. 11). The western arm of the Rocky Mountains is a high mountain chain that lies

between the structural basin to the east and the depression to the west.

The area of investigation lies between the smaller structural features of the western arm of the Rockies, the Nacimiento Mountains or uplift, and the Valles Caldera. The Valles Caldera is a depression about 12 to 15 miles in diameter, formed by eruption of a large volume of volcanic ash. The central part of the caldera collapsed and was later intruded by volcanics, which formed a series of intracaldera domes.

The Nacimiento Mountains were formed by faulting that took place to the west of the main mountain mass (Fig. 3). Renich[1] described the fault as an overthrust with most fault planes in this shear zone dipping to the east, showing that the mountain mass has been overthrust to the west toward the San Juan Basin. The overthrust is not a single fault; movement has taken place along several planes of shear. The fault has thrust the Precambrian rocks upward to a position in which they are adjacent to the younger Mesozoic rocks to the west. The stratigraphic displacement along the fault ranges from 3000 to 3500 ft.

Numerous smaller faults on the flanks of the mountains are contemporaneous with the overthrust, as is the Jemez fault along the southeastern edge of the area (Fig. 3). This northeast-trending fault parallels Jemez Creek, and is covered by younger volcanics to the north where it continues into the caldera. Near Jemez Springs the fault brings to the surface an outcrop of Precambrian gneiss.

Smith et al.[3] have indicated through work in the area that the Valles Caldera is bounded by ring faults in which the intracaldera blocks dropped down into the center of the caldera. The exposures of the faults are covered by younger volcanics, but probably constitute a complex fracture zone 2 to 3 miles wide. After this subsidence, intracaldera domes were intruded through this zone of weakness.

The Jemez Plateau is covered by Cenozoic volcanic rocks that obscure most of the structure. The test drilling and measured sections indicate a small north-south-trending basin near the center of the experimental site. The basin is characterized by the thickening of the Pennsylvanian rocks off the flanks of the mountain, and thinning to the east (Fig. 4). The basin may be structural in part (a faulted area) or erosional, where the upper surface of the Precambrian rock was cut to form a small valley. General structural features in the area indicate north-south lineations. The overlying Permian rocks appear to thicken eastward, off the flanks of the mountains. Except in the northwest corner of the area, the Mesozoic rocks were eroded from the Permian rocks before the explosive deposition of the Cenozoic volcanics.

The Precambrian, Pennsylvanian, and Permian rocks are probably arched upward along the outer rim of the caldera by welling of the magma through the central chamber. Within the caldera the eastern edge of the basin is truncated by the down-faulted ring-fault structure.

X. GEOLOGIC HISTORY

This brief geologic history of the area was condensed from Woods and Northrop[2] and Ross et al.,[4] with minor modifications.

The Precambrian rocks were deformed prior to the deposition of the earlier Paleozoic sediments. Subsequent erosion reduced the rocks to a peneplain, above which rose an occasional monadnock. Either some minor structural deformation occurred or an erosional valley was cut into the Precambrian surface near the center of the experimental area before the deposition of the Pennsylvanian rocks. The lower rocks of the Magdalena Group were deposited into the lowlands and shallow seas. These sediments thickened in the small basin. As the upper part of the Magdalena Group was being deposited, a positive land mass began to rise along the present position of the Nacimiento Mountains.

Subsidence of the basin to the east and west began to occur. Deposition of the Permian rocks (Abo Formation) followed, as sedimentation became continental--due to extensive filling of the basins. Mesozoic and Cenozoic sediments were also deposited.

The folding and deformation along the Nacimiento thrust-faults in the early Cenozoic Era caused the high mountain area to emerge. Subsequent erosion stripped off most of the Mesozoic rocks and all of the early Cenozoic sediments, cutting an irregular surface into the Abo Formation.

Volcanic activity then began in the Valles Caldera (Pliocene Epoch) with the extrusion of basalts, followed by latites and rhyolites. After a period of quiescence and erosion, catastrophic eruptions of hot ash-flows followed, resulting in formation of the Valles Caldera and capping of the Jemez Plateau with the Bandelier Tuff. The intracaldera domes were subsequently formed in the Valles Caldera. The caldera was then filled by lakes that have since been drained by headward erosion of Jemez and San Antonio Creeks. Erosion has modified the Jemez Plateau into a number of narrow mesas as we see it now.

TABLE I

GEOLOGIC LOG OF GRANITE TEST HOLE NO. 1

Elevation of land surface	-	8475 ft
Depth drilled	-	2575 ft
Hole diameter	-	13-3/4 in. to 280 ft 9-7/8 in. to 1600 ft 6-3/4 in. to 2410 ft 4-1/4 in. to 2575 ft
Casing Schedule	-	10-3/4 in. o.d. to 258 ft 7-5/8 in. o.d. to 1357 ft 5 in. o.d. to 2400 ft Open hole 2400 to 2575 ft
Drilled-Air-Mist Rotary	-	To 2410 ft
Core-Water Rotary	-	2410 to 2575 ft
Date Completed	-	June 30, 1972

	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tuff, gray, moderately welded, rhyolitic; crystals and crystal fragments of quartz and sanidine, rock fragments of pumice, rhyolite and latite, in ash matrix.	60	60
Abiquiu Tuff		
Sandstone, light gray, with pebbly conglomerate containing rock fragments of pumice, latite and rhyolite, and unidentified rock fragments ranging from light gray and green to dark gray and black.	100	160
Abo Formation		
Shale and fine-grained sandstone, some clay lenses; predominantly red to dark red in color, with some lenses of white to gray; arkosic with a few thin beds of limestone. Shale, dark red, 160 to 290 ft; sandstone, fine-grained, dark red, 290 to 350 ft; sandstone, fine-grained, alternating with shale, dark red, 350 to 680 ft; shale and sandstone, fine-grained, predominantly red, with lenses of white to gray shale and sandstone, a few thin beds of limestone, 680 to 1030 ft; clay, dark red with minor lenses of shale and sandstone, 1030 to 1070 ft.	910	1070

TABLE I (cont)

	Thickness (ft)	Depth (ft)
Magdalena Group		
Madera Limestones:		
Upper limestone member consists of limestone alternating with gray and red shales and sandstone, arkosic; limestone, gray, alternating with sandstone, fine-grained red, 1070 to 1250 ft; shale, red with some thin lenses of limestone, gray, 1250 to 1330 ft; limestone, gray, with some lenses of sandstone, fine-grained red, and shale, light red, 1330 to 1440 ft; shale, dark red, with lenses of limestone, dark gray, 1440 to 1530 ft; limestone, gray, with thin lenses of light red and gray sandstone, fine-grained, 1530 to 1670 ft.	590	1660
Lower limestone member consisting of dark gray limestone and thin lenses of white to gray shale and fine-grained sandstone. Limestone, dark gray, with thin lenses of sandstone, fine-grained, white to light gray and shale, dark gray.	155	1815
Sandia Formation		
Upper clastic member, limestone, gray, with lenses of gray shale and fine-grained sandstone ranging from light gray to light green.	235	2050
Lower limestone member, limestone, dark gray, siliceous, dense.	55	2105
Precambrian Rocks		
Augen gneiss, brownish gray, with inclusions of pink plagioclase, 2105 to 2430 ft; granite, reddish brown, medium-grained, 2430 to 2480 ft; gneiss, reddish brown, medium-grained, foliated, 2480 to 2520 ft; amphibolite, dark gray, fine-grained, 2520 to 2575 ft.	470	2575

TABLE II

GEOLOGIC LOG OF HOLE A

Elevation of land surface	- 8450 ft
Depth drilled	- 590 ft
Hole diameter	- 9-5/8 in. to 100 ft 6-1/4 in. to 590 ft
Casing schedule	- 7 in. o.d. to 97 ft 4-1/2 in. o.d. to 578 ft
Drilled - Mud, rotary	
Date completed	- April 10, 1972

	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tuff, light gray, nonwelded to moderately welded, rhyolitic; crystals and crystal fragments of sanidine and quartz, with rock fragments of pumice and latite, in gray ash matrix.	30	30
Abiquiu Tuff		
Sandstone, light gray, tuffaceous, friable; mafic minerals and a few quartz crystals; rock fragments of pumice, latite, and rhyolite in a fine ash matrix with mafic mineral altered to stain matrix light yellow, 50 to 100 ft. Conglomerate, light gray, tuffaceous, friable with rock fragments of quartzite and chalcedony, 100 to 155 ft.	125	155

TABLE II (cont)

	Thickness (ft)	Depth (ft)
Abo Formation		
Shale and silty sandstone, predominantly brownish-red to dark red in color, with some lenses of white and dark gray; arkosic, with minor amounts of quartz grains. Silty sandstone, brownish-red, 155 to 260 ft; shale, dark red, 260 to 320 ft; silty sandstone, red, 320 to 380 ft; shale, red, 380 to 460 ft; shale, dark red, 460 to 590 ft.	335	590

TABLE III

GEOLOGIC LOG OF HOLE B

Elevation of land surface	-	8625 ft
Depth drilled	-	650 ft
Hole diameter	-	9-5/8 in. to 100 ft 6-1/4 in. to 650 ft
Casing schedule	-	7 in. o.d. to 97 ft 4-1/2 in. o.d. to 566 ft
Drilled - Mud, rotary Date completed	-	April 13, 1972

	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tuff, light gray to gray, nonwelded to moderately welded, rhyolitic, containing crystals and crystal fragments of quartz and sanidine and rock fragments of pumice, latite, and rhyolite in an ash matrix. Tuff, gray, moderately welded, 0 to 140 ft; tuff, light gray, moderately welded, 140 to 230 ft; tuff, light gray, nonwelded, made up mostly of pumice, 230 to 380 ft.	380	380
Tschicoma Formation		
Latite, dark gray, vugs in places, with some calcite crystals; some thin lenses of light gray clay.	60	440
Abo Formation		
Shale and silty sandstone, dark red in color, with some lenses and clots of white and gray to dark gray, arkosic. Shale, dark red, 440 to 560 ft; silty sandstone, dark red, 560 to 650 ft.	210	650

TABLE IV

GEOLOGIC LOG OF HOLE C

Elevation of land surface	- 8700 ft
Depth drilled	- 750 ft
Hole diameter	- 9-5/8 in. to 100 ft 6-1/4 in. to 750 ft
Casing schedule	- 7 in. o.d. to 97 ft 4-1/2 in. o.d. to 750 ft
Drilled - Mud, rotary Date completed	- April 16, 1972

	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tuff, light tan and light gray to gray, nonwelded to moderately welded, rhyolitic, containing crystals and crystal fragments of quartz and sanidine and rock fragments of pumice, latite and rhyolite, in an ash matrix. Tuff, light gray, nonwelded, pumiceous, 0 to 30 ft; tuff, gray moderately welded, dense, 30 to 80 ft; tuff, light gray, moderately welded, pumiceous, 80 to 190 ft; tuff, light gray, nonwelded, made up mostly of pumice fragments, 190 to 240 ft.	240	240
Abiquiu Tuff		
Sandstone and conglomerate, light gray to gray, tuffaceous, containing sand grains of quartz, feldspar, and light- to dark-colored subrounded to rounded rock fragments, some of which are granite schist, quartzite in a fine-to-medium-grained matrix. Sandstone, light gray, tuffaceous friable, 240 to 410 ft; conglomerate, gray, made up mostly of pebble-size pumice, 410 to 480 ft; conglomerate, gray to dark gray, tuffaceous, containing rock fragments of pumice, granite, quartzite, schist, and dark igneous rock, unidentified, 480 to 580 ft.	340	580
Abo Formation		
Shale and fine-grained sandstone, red to dark red, with some lenses of light gray and white, arkosic. Shale, dark red, 580 to 620 ft; sandstone, fine-grained, alternating red and gray to white, 620 to 680 ft; shale, dark red, 680 to 750 ft.	170	750

TABLE V

GEOLOGIC LOG OF HOLE D

Elevation of land surface	- 7900 ft
Depth drilled	- 500 ft
Hole diameter	- 9-5/8 in. to 100 ft 6-1/4 in. to 500 ft
Casing schedule	- 7 in. o.d. to 97 ft 4-1/2 in. o.d. to 500 ft
Drilled - Mud, rotary	
Date completed	- April 18, 1972

	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tuff, gray, moderately welded, rhyolitic, containing crystals and crystal fragments of quartz and sanidine, mafic minerals, rock fragments of pumice, rhyolite and latite, in gray ash matrix.	120	120
Abo Formation		
Shale, fine-grained sandstone and clay, ranging from tan to dark red, with stringers and lenses of white and gray. Clay, dark gray, 120 to 190 ft; clay, tan, some mafic stains, and light pinkish clots, 190 to 200 ft; shale, light red with gray clay lenses, 200 to 240 ft; shale, red, with dark gray lenses of white shale, 240 to 280 ft; shale, red, with dark gray lenses of sandstone, 280 to 320 ft; shale, dark red, with lenses of white to gray shale, 320 to 390 ft; shale, dark red, 390 to 430 ft; sandstone, fine-grained, dark red, with lenses of dark gray, 430 to 460 ft; shale, dark red, 460 to 500 ft.	380	500

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