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GEOLOGY OF GEOTHERMAL TEST HOLE GT-2
FENTON HILL SITE, JULY 1974

by

W. D. Purtymun, F. G. West, and R. A. Pettitt

ABSTRACT

The test hole GT-2, drilled at the Fenton Hill Site, was completed at a depth of 6346 ft (1934.3 m) below land surface. The hole penetrated 450 ft (137.2 m) of Cenozoic volcanics, 1945 ft (592.8 m) of sediments of Permian and Pennsylvanian age and 3951 ft (1204.3 m) of granitic rocks of Precambrian age. This report presents the field geologic log of the hole and hydrologic data compiled during the drilling phase of the program.

I. INTRODUCTION

The second geothermal exploratory hole, GT-2, drilled by the Los Alamos Scientific Laboratory, is located on Fenton Hill about 2 miles (3.2 km) northwest of La Cueva, New Mexico (Fig. 1). The area is designated as the Fenton Hill Site, TA-57. The location of the site was based on investigations made in the area by the Laboratory.

This report presents data obtained during the test drilling phase through the volcanic, sedimentary and granitic sections of GT-2. The field geologic log and a brief description are presented of the stratigraphy, structure, and hydrology of the area. A regional description of geology and/or hydrology is found in Renick,[1] Woods and Northrop,[2] Smith et al.,[3] Ross et al.,[4] Bailey et al.,[5] Purtymun,[6] West,[7] and Purtymun et al.[8] The petrology of rock types of Precambrian age penetrated by test hole GT-1 are described by Perkins,[9] while Fitzsimmons[10] presents a general description of Precambrian rocks in the area. A regional geologic map was published by Smith et al.[11]

The drilling contractor and drilling support units do not use the metric system. As this report is prepared to be used as a working document by contractors for the drilling and construction of additional energy extraction holes, English units are used first to avoid confusion. Metric units are shown in parentheses. Depth measurements in the report are referred to land surface elevation of 8690 ft (2648.7 m).

II. GEOLOGY

This report describes the volcanic rocks of Cenozoic age, sediments of Permian and Pennsylvanian age, and granitic rocks of Precambrian age.

The log interpretation in the volcanic and sedimentary section was based on microscopic examination of the cuttings collected while using mud or air-mist-mud as a cuttings carrier (Table I). The log interpretation of the Precambrian section was based on microscopic examination of cuttings collected while using air and/or soap to a depth of 3550 ft (1082 m) and water and

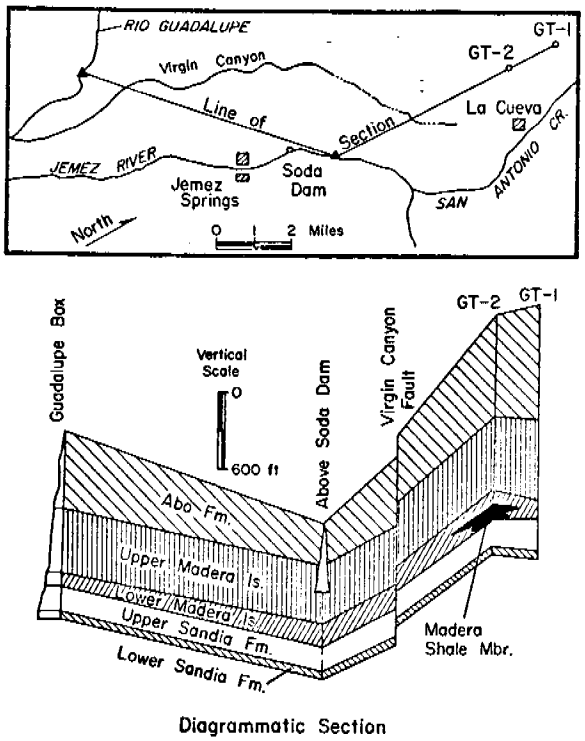

Fig. 1. Location of Test Hole GT-2 and diagrammatic section showing Permian and Pennsylvanian rock overlying Precambrian rocks.

drilling mud to a depth of 6346 ft (1934.3 m). Geophysical logs were used to adjust the contact between the different rock types (Table I).

A. Stratigraphy

Rock units penetrated by the test hole were (youngest to oldest) the Bandelier Tuff, the Paliza Canyon Formation, the Abiquiu Tuff, the Abo Formation, and the Madera Limestone and Sandia Formation of the Magdalena Group. Granitic and metamorphic rocks were penetrated in the Precambrian section.

1. Cenozoic Volcanics. The Bandelier Tuff forms the surface and upper part of the Jemez Plateau at the Fenton Hill Site. The tuff ranges from moderately welded to welded ashflows of rhyolitic tuff with an ash-fall of gray pumice. The tuff ranges in color from light to dark gray and consists of quartz and sanidine crystals with crystal fragments and lithic fragments of latite and pumice in an ash matrix. The pumice is composed of minor amounts of quartz and sanidine crystal fragments with some lithic inclusions of latite and rhyolite in a cellular structure of glass. The thickness of the Bandelier Tuff penetrated by GT-2 was 350 ft (106.7 m) (Table I).

The Paliza Canyon Formation underlies the Bandelier Tuff at the site. The Paliza Canyon Formation is composed of andesite and basaltic andesite breccias that are interbedded with sand and gravel. A part of the formation outcrops in a road cut in the canyon to the north of the site. The thickness of the formation penetrated by GT-2 was 50 ft (15.2 m).

The Abiquiu Tuff underlies the Paliza Canyon and is composed of a light gray, friable tuffaceous sandstone. In the upper part of the section, the sandstone is interbedded with angular fragments of basalt. The sandstone is composed of quartz, chalcedony, and fragments of rhyolite and quartzite in a tuffaceous matrix. The lower part contains rock fragments and pebbles derived from Precambrian crystalline rocks. The thickness penetrated by GT-2 was 50 ft (15.2 m).

2. Permian Rocks. The Abo Formation underlies the Abiquiu Tuff and is composed of a sequence of shales, siltstones and fine-grained sandstones with some clay lenses. The color of the sediments ranges from brownish-red to dark red, with the clays ranging from white to gray. Near the base of the formation are dark red lenses of clay interbedded with gray limestone. The thickness of the Abo penetrated by GT-2 was 780 ft (237.7 m).

3. Pennsylvanian Rocks. The Magdalena Group is composed of the Madera Limestone and the Sandia Formation, which at GT-2 are separated by a shale member.

The Madera Limestone is made up of an upper limestone and a lower limestone member. The upper limestone is composed of gray limestone and arkosic limestone alternating with gray and red arkosic shale. The thickness of the upper member at GT-2

was 610 ft (185.9 m). The lower limestone is a dark gray dense limestone with thin lenses of gray shale and white to gray fine-grained siltstone and sandstone. The thickness of the lower limestone at GT-2 was 115 ft (35.1 m).

The lower member of the Madera is underlain by a shale which has not been described in previous reports on the area. The shale has tentatively been placed in the lower part of the Madera. The shale member is dark gray shale with lenses of gray siliceous limestone and some lenses of gray clay and reddish-brown fine-grained sandstone. The shale is probably of only local extent and is equivalent in part to the lower limestone member of the Madera. The thickness of the shale member penetrated by GT-2 was 180 ft (54.9 m).

The Sandia Formation consists of an upper clastic member and a lower limestone member. The clastic member is a gray limestone and reddish-brown fine- to coarse-grained sandstone with lenses of brown shale and brown to greenish-gray clays. The thickness of the clastic member at GT-2 was 205 ft (62.5 m).

The lower limestone member consists of a light gray siliceous dense limestone with a few lenses of fine- to coarse-grained sandstone and light gray siltstone. The lower limestone overlies the Precambrian granitic rocks. There appears to be little if any weathering of the top granite immediately underlying the sediments. The thickness of the lower limestone at GT-2 was 55 ft (16.8 m).

4. Precambrian Rocks. As identified from the cuttings, the granitic rocks penetrated represent three general types: granites, granodiorites and monzonites. The identification is based on percentages of quartz, potassic feldspar (microcline, orthoclase), and sodic feldspar (plagioclase). The following criteria were used for identification of cuttings:

Granite:	quartz >10%
	potassic feldspar primary
	plagioclase, secondary
Granodiorite:	quartz >10%
	potassic feldspar = or <plagioclase
Monzonite:	quartz <10%
	potassic feldspar = plagioclase
	or if quartz >10%, the rock is a quartz monzonite.

Biotite is the major mafic mineral with minor amounts of hornblende. The metamorphic rocks penetrated in the lower section of the hole consisted of biotite-hornblende schist associated with some granitic gneiss. A thin section of amphibolite was penetrated in the lower section of the hole. Also identified in the cuttings were dikes or veins that were mainly biotite with hornblende and sodic feldspar.

Granites in general had the slowest drilling rates of 4 to 6 ft/h (1.2 to 1.8 m/h). The coarse-grained granites drilled slower than the fine-grained granites. Granodiorites had similar drilling rates, while the monzonites and schists were cut at 8 to 12 ft/h (2.4 to 3.7 m/h).

The granites tend to cut to the gauge of the bit except in sections containing large crystals of orthoclase or at contacts between units. The sections of the hole through the granodiorites, monzonites, schists, and thicker dikes tend to enlarge slightly due to erosion from the circulating fluids used as cutting carriers.

A comparison of the geologic log with the gamma log indicates a greater level of gamma activity in the granite than in other rock types. Coarse-grained granites (large orthoclase crystals) had higher gamma activity. Contacts between rocks of different textures (coarse- to fine- or medium-grained) had an observed gamma activity indicating the chill margin associated with emplacement of the granitic rocks.

The cores showed two major sets of joints or factures. One set was nearly horizontal and another set was about 60° from vertical. Some joints were plated with calcite or epidote; others appeared closed, with no mineralization. The granitic cores contained a slight gneissic structure which appeared nearly vertical.

The cores, each ranging from 5 to 20 ft (1.5 to 6.1 m) long, showed several textural or lithologic changes within the section of core. The descriptions of the rock types given on Table I are based on observations of cuttings. Small features such as textural changes, thin veins or dikes, joints or fractures, or slight lithologic changes could not always be characterized from the cuttings nor represented in this summary form.

B. Structure

The upper surface of the Jemez Plateau at the Fenton Hill Site is dissected into elongated mesas by the southwest-trending intermittent streams. The site is located on one of these mesas and is underlain by the Bandelier Tuff. The tuff thins to the west and southwest from the source area (Valles Caldera) which lies to the east of the site.

The upper surface of the Abo Formation was deeply eroded prior to the emplacement of the overlying Cenozoic volcanics. Since the Abiquiu Tuff and Paliza Canyon Formations were deposited on this irregular surface, they vary in thickness across the area and in some locations may be absent.

Generalized contours on top of the Abo Formation (using test holes GT-1, GT-2, A and D for control, as well as outcrop elevations) show that the surface of the Abo dips gently to the southwest (Fig. 2).

A north-south trending normal fault occurs east of the site along the west wall of the canyon cut by San Antonio Creek. The fault is downthrown to the east with an apparent throw that ranges from 300 to 400 ft (91.4 to 121.9 m).

Along the Jemez River to the southeast of the site, the base of the volcanics is 300 to 500 ft (91.4 to 152.4 m) below the basal contact at the site. This displacement is due in part to the erosion of the top of the Abo prior to the emplacement of the volcanics and in part to a fault along Virgin Canyon that is downthrown to the east. The fault has had some apparent reverse movement since the emplacement of the Bandelier Tuff. The tuff that forms the elongated mesa to the southeast of Virgin Canyon is about 50 ft (15.2 m) higher than the surface of the mesa to the northwest of the canyon. The Abo thickens to the north and northwest of the site and thins to southwest and southeast of the site (Fig 1). Thicknesses of the section are shown in Table II.

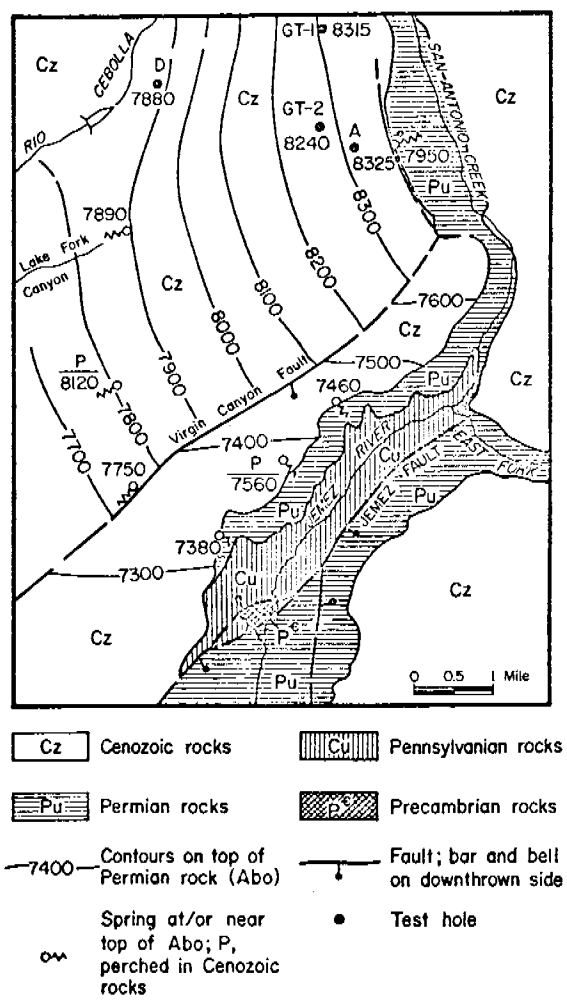

Fig. 2. Geologic map of area with structure contours on top of Abo Formation.

The members of the Madera Limestone and Sandia Formation vary in thickness, but in general thin rapidly to the west from the western edge of an old depositional basin and to the east and south of the site at Fenton Hill. The site is located near the axis of the north-south trending depositional basin that is truncated by the ring-fault structure formed by the Valles Caldera to the east (Fig. 3). The basin may be either structural in origin as the result of faulting or erosion of the granitic rocks prior to the deposition of the sediments of Pennsylvanian age.

The Jemez Fault trends northeast along the east side of the Jemez River (Fig. 3). It is one of the major faults in the area, being a normal fault that is downthrown to the east. Renick estimated the throw to be about 8000 ft (2438.4 m) in an area about 12 miles (19.3 km) to the south.[1] The throw

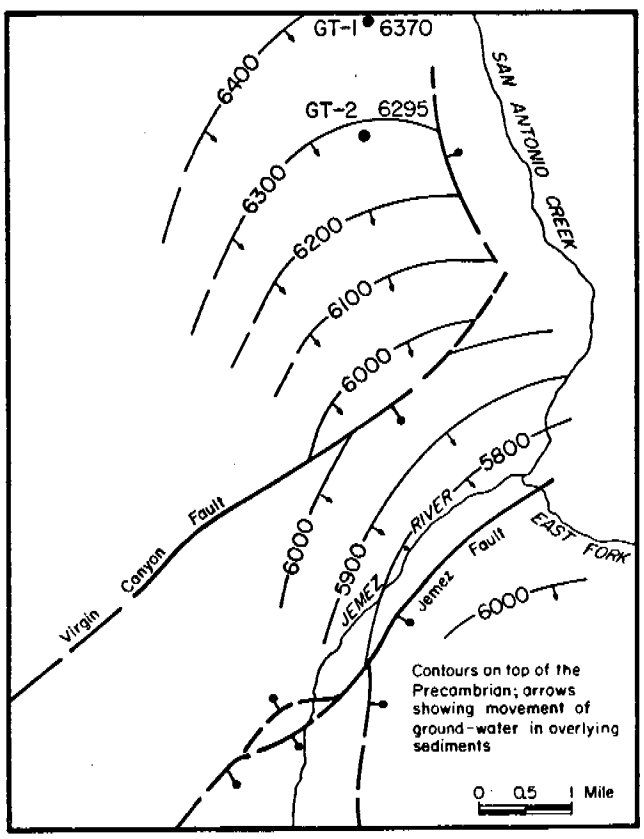

Fig. 3. Structure contours on top of Precambrian rocks showing direction of groundwater movement in overlying sediments.

along the Jemez River is about 800 to 1000 ft (243.8 to 304.8 m) based on displacement of the Permian and Pennsylvanian sediments.

III. HYDROLOGY

The hydrologic interpretation is based on geophysical logs in the volcanic and sedimentary sections. Perched water was encountered in the Cenozoic volcanics, the Abo Formation, and the upper limestone member of the Madera Limestone. The zone of saturation occurred in the lower limestone and shale member of the Madera and in the Sandia Formation. Fracture zones in the Precambrian rocks may contain small amounts of water.

A. Cenozoic Volcanics

Geophysical logs indicated a 40-ft (12.2 m) saturated section of the Abiquiu Tuff from a depth of 410 to 450 ft (125.0 to 137.1 m). The Bandelier Tuff and the Paliza Canyon Formations, which lie above the Abiquiu Tuff, did not contain perched water. Water in the Abiquiu is perched on the underlying shale, siltstone, and fine-grained sandstone of the Abo Formation.

The Abiquiu Tuff is a loosely consolidated, friable tuffaceous sandstone. The caliper log through the Abiquiu section indicated an enlarged hole with considerable washout of the friable material. The electric log indicated porosity filled with fresh water. Water in the volcanics moves downslope filling the low areas, while some of the high areas of the Abo may be above the water table.

Generalized contours on top of the Abo, in the area of the Fenton Hill Site, indicate that the surface of the formation dips to the west-southwest at about 80 ft/mi (15 m/km) (Fig. 2). Thus, the water in the volcanics perched on the Abo will move in that direction. The spring-seeps in Lake Fork and Virgin Canyons discharge from the volcanics overlying the Abo. This discharge forms perennial streams that flow into the Rio Cebolla and Rio Guadalupe. The spring at elevation 8120 ft (2475 m) is perched in

the volcanics. Test hole D contains water in the volcanics which rises to a depth of ~30 ft (9.1 m) below land surface (Fig. 2). The hole was cased to 100 ft (30.5 m) leaving about 20 ft (6.1 m) of the hole open in the volcanic section above the Abo.

The groundwater divide in the volcanics between the Fenton Hill Site and the valley cut by San Antonio Creek occurs along a north-south trending fault (Fig. 2). The spring at the base of the volcanics on the downthrown side at elevation 7950 ft (2423 m), Horseshoe Springs, discharges from the base of the volcanics.

The groundwater divide in the volcanics to the south and southeast of the Fenton Hill Site occurs along the Virgin Canyon Fault. Here, the base of the volcanics is 300 to 500 ft (91.4 to 152.4 m) below the basal contact at the site. Springs at elevations 7300 ft (2225 m) and 7460 ft (2274 m) discharge from the base of the volcanics while the spring at 7560 ft (2304 m) discharges from a perched zone in the volcanics.

The springs at elevations 7300 ft (2225 m) and 7460 ft (2274 m) are used for water supply at Jemez Springs. The quality of water in the volcanics is good, dissolved solids concentration is less than 500 mg/ℓ.

B. Abo Formation

Geophysical logs indicated several perched zones of water in the Abo Formation. The water is in fine-grained sandstones which are underlain by shales. The permeability of the fine-grained sandstones is low, probably less than 10 gpd/ft^2 (0.41 m/d). The saturated intervals are 30 ft (9 m) or less in thickness and would yield very little water to a well. The electric logs indicate that the saturated intervals occur at depths of 780 to 800 ft (237.7 to 243.8 m); 970 to 995 ft (295.7 to 303.3 m); 1005 to 1015 ft (306.3 to 309.4 m), and 1100 to 1120 ft (335.3 to 341.4 m) below land surface at GT-2.

The total dissolved-solids concentration of the water in the Abo may range from 300 to 1000 mg/ℓ, based on data collected on quality of water in the area.

C. Magdalena Group

The Magdalena Group contains several perched water zones in the Upper Madera Limestone, while the Lower Madera, the shale member, and the Sandia Formation are in the zone of saturation above the Precambrian granitic rocks.

1. Madera Limestone. Geophysical logs indicate six perched zones in the upper limestone member above the main zone of saturation overlying the granitic rocks. No hydrologic characteristics of the water in these zones were determined, as the hole was drilled using mud as the cuttings carrier. The electric logs indicate that the perched zones occur at depths of 1245 to 1260 ft (379.5 to 384.0 m), 1290 to 1295 ft (393.2 to 394.7 m), 1320 to 1345 ft (402.3 to 410.0 m), 1595 to 1620 ft (486.2 to 493.8 m), 1715 to 1745 ft (522.7 to 531.9 m), and 1780 to 1790 ft (542.5 to 545.6 m) below land surface. The lithologic logs show that these water zones are in limestone that is probably underlain by shales or clays. The perched zones are of limited extent and comprise thicknesses of less than 25 ft (7.6 m).

When drilled to a depth of 1905 ft (580.6 m) the hole was cased to a depth of 1590 ft (484.6 m) below land surface. The three water-bearing zones above 1590 ft (484.6 m) were sealed off when the casing was cemented by pumping cement through a packer set near the casing shoe.

The dense limestone of the lower limestone member was encountered at a depth of 1840 ft (560.8 m). At a depth of 1905 ft (580.6 m) the carrier fluid was lost and circulation of fluid could not be regained to drill to the granitic basement until a number of cement plugs were placed.

The zone of saturation above the granitic rocks is in the lower limestone and shale members of the Madera and Sandia Formation. The water level after the casing was set at 1590 ft (484.6 m) was about

1750 ft (533.4 m). This probably reflects the artesian head in the zone of saturation which was encountered in the lower limestone member at a depth of 1840 ft (560.8 m). The slight variation of water levels at 1750 ft (533.4 m), measured after the casing was set at 1590 ft (484.6 m), indicated that water in the limestone is under artesian head.

The water in the zone of saturation is moving to the southeast on top of the Precambrian granitic rocks (Fig. 3). The small displacement of the Virgin Canyon Fault has little effect on the movement of water; however, the Jemez Fault that lies to the east of the Jemez River and intersects the river at Soda Dam forms a discharge boundary for water in the zone of saturation. The fault is downthrown to the east and down-drops the relatively impermeable sediments of the Abo Formation against the permeable rocks in the zone of saturation to the west. The discharge of water from the zone of saturation occurs along the Jemez River from the confluence of San Antonio Creek and the East Fork of the Jemez to Soda Dam. The major part of the discharge occurs at Soda Dam. The discharge along the Jemez Fault from the zone of saturation (Lower Madera Limestone and Sandia Formation) is ≈5 cfs (142 ℓ/sec) based on records from U. S. Geological Survey gaging stations on the Jemez River.

Fluid loss in the lower limestone member indicated a field coefficient of permeability of about 1000 gpd/ft^2 (4.1 m/d), and an estimated transmissibility of about 115 000 gpd/ft (1426 m^2/d) of the 115 ft (35.1 m) section of dense limestone. The permeability is due to open fractures or joints.

The velocity of water in the lower limestone aquifer can be estimated using the field coefficient of permeability, the hydrologic gradient of the aquifer, and the porosity by means of a method described by Wenzel.[12]

$$V = \frac{PI}{p}$$

where V = velocity in ft per day
P = field permeability, gpd/ft^2
I = hydrologic gradient, ft per ft
p = porosity of the aquifer, percent.

The hydrologic gradient is about 100 ft/mi (18.9 m/km). The porosity of the limestone (fracture) is estimated to be about 20%. Thus the velocity is computed as follows

$$V = \frac{(1000)(.017)}{(0.20)(7.48)}$$

or

V = ~11 ft/d (3.4 m/d) or 4015 ft/yr (1224 m/yr).

Using a velocity of 4000 ft/yr (1219 m/yr), it would take about 6 yr for the water in the aquifer at GT-2 to move into the discharge area along the Jemez River.

2. Sandia Formation. The Sandia Formation lies within the zone of saturation above the granitic rocks. Geophysical logs to indicate water-bearing characteristics were not run through the Sandia section, nor were there any hydrologic tests made in the section.

3. Quality of Water. The water in the Madera Limestone is high in total dissolved solids (Table III). Shown in the table is the quality of water from a spring discharging from the Upper Madera, the zone of saturation in the Lower Madera limestone, and the thermal spring at Soda Dam (zone of saturation). As the water moves down-gradient to the discharge area, it becomes highly mineralized. Temperatures in the zone of saturation are high. The aquifer would be classified as thermal.

D. Precambrian Rocks

The test hole had been drilled with air (or air and soap) to a depth of 3510 ft (1069.8 m) when the cement broke loose from casing set into the granite. This allowed water from the sediments to enter the hole.

Fracture zones in the granitic rock above 3510 ft (1069.8 m) also yielded some water. Drilling was continued with air and/or air and water to about 4020 ft (1225.3 m); the remainder of the hole was drilled using water with added drilling mud.

1. Fracture Zones. Geophysical logs (nuclear, 3-D velocity, density, electric, and caliper) were used to identify fracture zones (Table IV). Drilling mud and lost-circulation material was added to the circulation fluids at a depth of 4020 ft (1225.3 m). Fluid loss prior to addition of mud and lost-circulation material was ~10 gpm (0.6 ℓ/sec). After the mud program was introduced, the losses decreased ~1-2 gpm (0.06 ℓ/sec). Temperature anomalies indicate nine zones were taking drilling fluids on July 13 (Table IV). These were at depths of 3185 ft (970.8 m); 3214 ft (979.6 m); 3410 ft (1039.4 m); 3550 ft (1082.0 m); 3574 ft (1089.4 m); 3590 ft (1094.2 m); 4198 ft (1279.6 m); 4352 ft (1326.5 m); and 4458 ft (1358.8 m). The other zones were plugged with drilling mud or cement; however, a reduction of fluid head in the hole will probably result in reopening the fracture and allow fluid entrance into the hole.

The coefficient of transmissibility in the granite section of the hole was estimated by the Slug-Injection Test in a method described by Ferris and Knowles.[13] The method utilizes fluid decline with time. The initial test was made at a depth of 4010 ft (1222.2 m) when water was being used as a cuttings carrier. The remainder of the tests were made after drilling mud was added to the fluid carrier. Except during the first test when declines were measured with a sounder, the remainder of the measurements were taken with a transducer which was attached to the bottom hole temperature sonde. The results of the test are shown in the following table.

Zone Tested (ft)		Estimated
From*	To	Coefficient of Transmissibility
2520 (768.1 m)	4010 (1222.2 m)	4.4 gpd/ft (.055 m^2/d)
2520 (768.1 m)	4545 (1385.3 m)	2.6 gpd/ft **(.032 m^2/d)
2520 (768.1 m)	5210 (1588.0 m)	2.2 gpd/ft (.027 m^2/d)
2520 (768.1 m)	5470 (1667.3 m)	2.5 gpd/ft (.031 m^2/d)
2520 (768.1 m)	5980 (1822.7 m)	3.7 gpd/ft (.046 m^2/d)

* Bottom of casing set in granite.

**Average of two slopes in curve; 4.2 gpd/ft decreased to 1.1 gpd/ft after 5 hours of decline.

In general an increase in thickness of interval tested did not change the transmissibility significantly. The drilling mud decreased the permeability of the fracture zones as the drilling of the hole progressed. The transmissibilities are very low, indicating a very low permeability in the granitic rocks.

2. Bulk Permeability. The lower section of the hole contains schists and quartz monzonites which were intruded by a small mass of granitic rocks. Geophysical logs indicated two permeable sections from depths of 5600 to 5690 ft (1706.9 to 1734.3 m) and from 6000 to 6050 ft (1828.8 to 1844.0 m). These zones may contain some water or the anomalies may instead indicate the invasion of drilling fluids into these slightly permeable schists and monzonites. Temperature anomalies obtained through these sections on July 13 showed that the rocks were taking drilling fluids.

3. Quality of Water. Several samples of water were collected from the granitic section. However, there may have been either some contamination with drilling fluids or some change in concentration of solids by evaporation as the fractures were releasing small amounts of water into the hole while drilling was being done with air. Partial analyses are shown in Table V, with two analyses of drilling fluid for comparison. In general, the mineral concentrations decreased with depth although they still are considered quite high.

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TABLE I

FIELD GEOLOGIC LOG OF TEST HOLE GT-2

ELEVATION OF LAND SURFACE 8690 FT (2648.7 m)

	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tuff, dark gray, moderately welded to welded, rhyolitic crystal and crystal fragments of quartz and sanidine, lithic fragments of pumice, rhyolite, and latite in ash matrix. Pumice, light gray with lithic fragments of light to dark gray rhyolite. Moderately welded tuff 0 to 110 ft; pumice 110 to 250 ft; welded tuff 250 to 295 ft; moderately welded tuff 295 to 325 ft; welded tuff 325 to 350 ft.	350 (106.7 m)	350 (106.7 m)
Paliza Canyon Formation		
Andesites and basaltic andesite breccia, dark gray, with interbedded sands and gravels.	50 (15.2 m)	400 (121.9 m)
Abiquiu Tuff		
Sandstone, light gray tuffaceous, friable, with angular basalt in upper part of section, crystal fragments of quartz, sanidine, and chalcedony; lithic fragments of rhyolite and quartzite in tuffaceous sand matrix.	50 (15.2 m)	450 (137.1 m)
Abo Formation		
Shale, siltstone, and fine-grained sandstone, brownish-red to dark red, with lenses of white to gray shale; clay lenses, dark red, with thin limestone lenses, gray, near base. Shale, dark red with thin lenses of white to gray shale and clay, 450 to 495 ft; siltstone and fine-grained sandstone, brownish-red, arkosic, 495 to 600 ft; shale, dark red, alternating with lenses of silty sandstone and siltstone and thin lenses of white to gray shale, 600 to 775 ft; sandstone, dark red, fine-grained, 775 to 800 ft; shale, dark red, alternating with lenses of silty sandstone and siltstone, 800 to 965 ft; sandstone, dark red, fine-grained, 965 to 1005 ft; shale, brownish-red, alternating with fine-grained silty sandstone, and thin lenses of limestone, gray, 1005 to 1095 ft; sandstone, red, fine-grained with lenses of thin limestone, gray, 1095 to 1130 ft; shale, red with lenses of fine-grained sandstone, thin lenses of white to gray shale and limestone, gray, 1130 to 1230 ft.	780 (237.7 m)	1230 (374.9 m)
Magdalena Group		
Upper limestone member consists of limestone, alternating with shale, fine-grained sandstone, and clay. Limestone, gray, alternating with thin lenses of sandstone, reddish-brown, fine-grained, and shale, red, 1230 to 1360 ft; clay, gray with thin lenses of limestone, gray, dense, 1360 to 1390 ft; limestone, gray, dense, arkosic, and shale, reddish-brown, with thin lenses of sandstone, reddish-brown, fine-grained, 1390 to 1580 ft; limestone, gray, dense, arkosic, 1580 to 1625 ft; clay, gray, with thin lenses of limestone, gray, dense, 1625 to 1650 ft; limestone, gray, dense with thin lenses of sandstone, reddish-brown, fine-grained, 1650 to 1700 ft;		

TABLE I (Continued)

	Thickness (ft)	Depth (ft)
Magdalena Group (continued)		
limestone, gray, dense, alternating with shale, dark red, sandstone, fine-grained, brown-red, and clay, dark gray, 1700 to 1840 ft.	610 (185.9 m)	1840 (560.8 m)
Lower limestone member consists of limestone, dark gray, dense, with thin lenses of shale, dark gray, and sandstone, white to gray, fine-grained.	115 (35.1 m)	1955 (595.9 m)
Shale member, (not previously described in area) shale, dark gray with thin lenses of limestone, gray, dense, siliceous, and siltstone, reddish-brown and clay, dark gray.	180 (54.9 m)	2135 (650.8 m)
Sandia Formation		
Upper clastic member consists of limestone, gray with sandstone, reddish-brown, fine- to coarse-grained, with shales, brown, and clays brown to greenish gray.	205 (62.5 m)	2340 (713.2 m)
Lower limestone member consists of limestone, light gray, siliceous, dense, with a few thin lenses of sandstone, fine- to coarse-grained, and siltstone, light gray.	55 (16.8 m)	2395 (730.0 m)
Precambrian Rocks		
Granites, granodiorites, monzonites, quartz monzonites, gneiss, schist and amphibolites with dikes of biotite-hornblende-pagioclase. Granite, light pinkish-red, 2395 to 2540 ft; granodiorite, light gray, 2540 to 2600 ft; granite, light pink coarse-grained, 2600 to 2615 ft; granodiorite, light pink, 2715 to 2730 ft; granodiorite, light gray, 2730 to 2745 ft; granite, pink, coarsed-grained, 2745 to 2765 ft; granodiorite, gray, 2765 to 2805 ft; granite, pink, coarse-grained, 2805 to 2930 ft; granodiorite, gray, 2930 to 2990 ft; monzonite, light gray, 2990 to 3030 ft; granodiorite, gray (dike ~3120 to 3123 ft), 3030 to 3175 ft; granite, pink, coarse-grained, 3175 to 3195 ft; granodiorite, gray, 3195 to 3260 ft; granite, pink, coarse-grained (dike ~3260 to 3265 ft), 3260 to 3340 ft; granodiorite, light gray, 3340 to 3375 ft; granite, pink (dike ~3495 to 3500 ft), 3375 to 3520 ft; granite, light pink, coarse-grained, alternating with granite, gray, fine-grained, 3520 to 3695 ft; granite, light gray, fine-grained, 3695 to 3755 ft; granite, light pink to light gray, 3755 to 3855 ft; granite, light gray with intervals of granite, pink, coarse-grained, 3855 to 3915 ft; granite, light pinkish-gray, 3915 to 3980 ft; granite, gray, 3980 to 4010 ft; granite, pink, coarse-grained, 4010 to 4030 ft; granite, light pinkish-gray, 4030 to 4210 ft; granite, light pink to light gray, coarse-grained [altered (weathered?) 4285 to 4290 ft]; 4210 to 4290 ft; granite, dark gray (thin dikes in interval), 4290 to 4350 ft; granite, gray, 4350 to 4480 ft; granite, light pinkish-gray, 4480 to 4610 ft; granite, light gray, 4610 to 4685 ft; granite, light pink, 4685 to 4750 ft; granite,		

TABLE I (Continued)

	Thickness (ft)	Depth (ft)
Precambrian Rocks (continued)		
light gray, 4750 to 4965 ft; granite, pink, coarse-grained, 4965 to 5000 ft; granite, light pinkish-gray, 5000 to 5095 ft; granite, gray, 5095 to 5165 ft; granite, light pinkish-gray, 5165 to 5240 ft; granite, light pink, coarse-grained, 5240 to 5265 ft; granite, dark gray, fine-grained, 5265 to 5275 ft; granite, pink, 5275 to 5335 ft; granite, dark gray, fine-grained, 5335 to 5345 ft; granite, light pink, 5345 to 5400 ft; granite, brownish-gray, coarse-grained, 5400 to 5410 ft; granite, light pink, 5410 to 5430 ft; granite, light pinkish-gray, 5430 to 5480 ft; granite, light pink, 5480 to 5520 ft; granite, light gray, 5520 to 5530 ft; granite, pink, coarse-grained, 5530 to 5545 ft; schist, biotite, hornblende, dark gray, 5545 to 5580 ft; granite, light pink, coarse-grained, 5580 to 5590 ft; schist, biotite, hornblende, dark gray, 5590 to 5605 ft; granite, light pink, coarse-grained, 5605 to 5615 ft; schist, biotite, hornblende, dark gray, 5615 to 5680 ft; amphibolite, olive gray, 5680 to 5705 ft; granite, light gray, 5705 to 5770 ft; granite, light pink, 5770 to 5800 ft; schist, biotite, hornblende, dark gray, 5800 to 5815 ft; granite, pink, coarse-grained, 5815 to 5825 ft; granite, light gray, 5825 to 5845 ft; dike, biotite, hornblende, plagioclase-orthoclase, 5845 to 5850 ft; granite, light gray, 5850 to 5875 ft; granite, gray, 5875 to 5895 ft; granite, pink, coarse-grained, 5895 to 5910 ft; schist, biotite, hornblende, gray, 5910 to 5950 ft; granite, pink, coarse-grained, 5950 to 5960 ft; gneiss, gray, alternating with schist, dark gray, 5960 to 5990 ft; quartz monzonite, light pinkish-gray, altered, 5990 to 6050 ft; quartz monzonite, pink, 6050 to 6145 ft; schist, biotite, hornblende, gray, 6145 to 6170 ft; granite, light pinkish-gray, 6170 to 6220 ft; granite, light pink, 6220 to 6245 ft; gneiss, gray, 6245 to 6255 ft; granite, light pink, 6255 to 6346 ft.	3951 (1204.3 m)	6346 (1934.3)

TABLE II

THICKNESS OF GEOLOGIC FORMATION

Geologic Formation	Section Thickness in Ft				
	GT-1	GT-2	Above Soda Dam	Guadalupe Box	Seven Mi (11.2 km) West of GT-2
Abo Formation	910 (277.4 m)	780 (237.7 m)	300 (91.4 m)	590 (179.8 m)	700 (213.4 m)
Madera Limestone					
Upper Ls. Mbr.	590 (179.8 m)	610 (185.9 m)	450 (137.2 m)	610 (185.9 m)	340 (103.6 m)
Lower Ls. Mbr.	155 (47.2 m)	115 (35.1 m)	200 (61.0 m)	120 (36.6 m)	--
Shale Mbr.	--	180 (54.9 m)	--	--	--
Sandia Formation					
Upper Clastic Mbr.	235 (71.6 m)	205 (62.5 m)	210 (64.0 m)	200 (61.0 m)	--
Lower Ls. Mbr.	55 (16.8 m)	55 (16.8 m)	30 (9.1 m)	30 (9.1 m)	--

TABLE III

CHEMICAL QUALITY OF WATER

	JF-1	GT-2	Soda Dam
Analysis	3-29-74	3-18-74	3-29-74
Silica (mg/ℓ)	40	115	42
Calcium (mg/ℓ)	115	78	320
Magnesium (mg/ℓ)	10	42	16
Sodium (mg/ℓ)	210	550	850
Carbonate (mg/ℓ)	0	0	0
Bicarbonate (mg/ℓ)	464	1230	1200
Sulfate (mg/ℓ)	30	200	38
Chloride (mg/ℓ)	290	400	1480
Fluoride (mg/ℓ)	2.6	3.1	3.3
Nitrate (mg/ℓ)	0	0	0
Hardness (mg/ℓ)	330	370	860
Total Dissolved Solids (mg/ℓ)	1100	2500	4000
Conductance (μmhos)	1700	2920	5900
pH	6.9	7.4	6.6
Temperature (°C)	16	56	46

JF-1 - Spring Upper Madera Limestone, Jemez River

GT-2 - Lower Madera Limestone

Soda Dam - Thermal Spring on Jemez Fault (Zone of Saturation)

TABLE IV

FRACTURE ZONES CONTAINING FLUIDS
(POTENTIAL AQUIFERS)

Internal (ft) From	Internal (ft) To	Thickness (ft)	Temp. Anomalies 6-25	Temp. Anomalies 7-8	Temp. Anomalies 7-13
2710 (826.0 m)	2718 (828.4 m)	8 (2.4 m)			
2930 (893.1 m)	2948 (898.6 m)	18 (5.5 m)			
2980 (908.3 m)	3008 (916.8 m)	28 (8.5 m)			1/
3012 (918.1 m)	3024 (921.7 m)	12 (3.6 m)			1/
3065 (934.2 m)	3070 (935.7 m)	5 (1.5 m)			
3082 (939.4 m)	3092 (942.4 m)	10 (3.0 m)			
3105 (946.4 m)	3113 (948.8 m)	8 (2.4 m)			
3185 (970.8 m)	3198 (974.8 m)	13 (4.0 m)	1/	1/	1/
3214 (979.6 m)	3232 (985.1 m)	18 (5.5 m)	1/	1/	1/
3410 (1039.4 m)	3424 (1043.6 m)	14 (4.2 m)			1/
3550 (1082.0 m)	3560 (1085.0 m)	10 (3.0 m)	1/	1/	1/
3574 (1089.4 m)	3580 (1091.2 m)	6 (1.8 m)	1/	1/	1/
3590 (1094.2 m)	3600 (1097.2 m)	10 (3.0 m)	1/	1/	1/
3645 (1111.0 m)	3658 (1114.0 m)	13 (4.0 m)	1/		
3732 (1137.5 m)	3738 (1139.3 m)	6 (1.8 m)	1/		
3848 (1172.9 m)	3858 (1175.9 m)	10 (3.0 m)	1/		
4008 (1221.6 m)	4012 (1222.8 m)	4 (1.2 m)			
4198 (1279.6 m)	4220 (1286.3 m)	22 (6.7 m)	1/	1/	1/
4352 (1326.5 m)	4384 (1336.2 m)	32 (9.7 m)	1/	1/	1/
4458 (1358.8 m)	4470 (1362.4 m)	12 (3.6 m)	1/	1/	1/
4510 (1374.6 m)	4540 (1383.8 m)	30 (9.2 m)			
4940 (1505.7 m)	4960 (1511.8 m)	20 (6.1 m)	1/	1/	
5340 (1627.6 m)	5352 (1631.2 m)	12 (3.6 m)	1/	1/	
5548 (1691.0 m)	5562 (1695.2 m)	14 (4.2 m)			2/
5664 (1726.4 m)	5676 (1730.0 m)	12 (3.6 m)			
5846 (1781.9 m)	5852 (1783.7 m)	6 (1.8 m)			
5885 (1793.8 m)	5895 (1796.8 m)	10 (3.0 m)			2/
5986 (1824.5 m)	6014 (1833.0 m)	28 (8.5 m)			2/
6025 (1836.4 m)	6030 (1837.9 m)	5 (1.5 m)			2/
6042 (1841.6 m)	6048 (1843.4 m)	6 (1.8 m)			2/
6062 (1847.7 m)	6068 (1849.5 m)	6 (1.8 m)			
6084 (1854.4 m)	6088 (1855.6 m)	4 (1.2 m)			

1/ Temperature anomalies indicate cooling as drilling fluid moves into the fractures. LASL temperature log 6-25-74 run to a depth of 5484 ft (1671.5 m); LASL temperature log 7-8-74 run to a depth of 6118 ft (1864.8 m); Birdwell temperature log run to a depth of 6344 ft (1933.6 m).

2/ Temperature anomalies ~5500 to 5650 ft (~1674 to 1722 m) and ~6000 to 6050 ft (~1829 to 1844 m) due to change in rock type and invasion of drilling fluids.

TABLE V

QUALITY OF WATER

Date	Depth (ft)	Conductance (μmhos)	Dissolved Solids (mg/ℓ)	Chloride (mg/ℓ)
4-16	1/	5080	4230	1200
4-23	2800 (853.4 m)	21900	--	3400
4-27	1/	6400	--	--
5-3	2400 (731.5 m)	18800	14900	2750
5-14	3200 (975.4 m)	12800	8800	3800

1/ Drilling Fluid

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