GL01221

LA-5819-PR
Progress Report

UC-13
Reporting Date: December 1974
Issued: January 1975

Planning, Drilling, and Logging of Geothermal Test Hole GT-2, PHASE I

by

Roland A. Pettitt

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

An Equal Opportunity Employer

In the interest of prompt distribution, this report was not edited by the Technical Information staff.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22151
Price: Printed Copy $4.00 Microfiche $2.25

PLANNING, DRILLING, AND LOGGING OF GEOTHERMAL TEST HOLE GT-2, PHASE I

by

Roland A. Pettitt

ABSTRACT

Geothermal Test Hole No. 2 (GT-2) is a deep exploratory hole drilled into the Precambrian-age basement granitic rocks of the Jemez Mountains in north-central New Mexico. The purpose of the hole is to confirm the suitability of the Fenton Hill Site for development of the world's first dry hot rock geothermal energy experiment. Due to recent volcanic activity in the area, the near-surface rocks still retain a great amount of heat. The drilling of GT-2 was required to obtain additional information on the geology and the heat flow characteristics of the area, and to determine the problems involved in drilling and taking core samples in the granitic basement rocks and the overlying sedimentary formations. Squeezing clay layers, caving shale beds, and lost-circulation zones provided difficult drilling conditions in the upper section of the hole. It had been planned to drill the Precambrian granitic rocks with compressed air as the circulation medium, but higher than anticipated water flows at depth forced abandonment of this method in favor of a fluid circulation medium. Various diagnostic logging techniques proved to be of invaluable assistance in determining formation characteristics. This report describes the first phase of the drilling and logging operations in GT-2.

I. INTRODUCTION

The earth's volume is about one trillion cubic kilometers, and all but a relatively thin crust on its outermost surface is at or above the melting temperatures of the rocks and metallic alloys that compose it. The earth's interior, then, is a tremendous reservoir of thermal energy, which is inherently clean because it already exists as heat. It is not necessary to burn a fuel or operate a reactor to produce it, and at sufficient depth it exists everywhere. Geothermal energy is potentially capable of contributing very significantly to the solution of many of man's most urgent power and pollution problems.

However, no practical method has yet been devised to utilize the energy in the dry solid rock of the earth's crust that is heated by the slow decay of the natural radioactive minerals which it contains, and by the normal flow of heat from still deeper in the earth's interior.

This report describes the work done and the problems encountered in drilling the first phase of exploratory hole GT-2 (Geothermal Test No. 2), a deep exploratory hole into the Precambrian-age granitic basement rocks. The purpose of the hole is to confirm the suitability of the Fenton Hill Site in New Mexico's Jemez Mountains for development of the world's first dry hot rock geothermal demonstration.

II. LOS ALAMOS DRY GEOTHERMAL SOURCE DEMONSTRATION PROJECT

A. Primary Objective

The primary objective of the Los Alamos Dry Geothermal Source Demonstration Project is to investigate and develop methods of extracting energy economically from hot rock in the earth's crust. This will involve large-scale field studies and demonstrations of drilling into hot rock, fracturing it by hydraulic pressure, or by other methods, to produce connected circulation paths through the rock, and then circulating water or other fluids through these channels to extract heat from the rock and transport it to the earth's surface. It will include research and development in those areas of geochemistry, geophysics, heat flow, fluid flow, rock mechanics, seismology, environmental effects, and related subjects, which are required to make such an energy extraction system successful, economical, and environmentally acceptable.[1,2]

Throughout the life of the project, a major objective will be to make this new technology available to industry as soon as its usefulness has been demonstrated.

B. Goals

The initial goal of the project is to produce and demonstrate an experimental geothermal energy extraction system of a type suitable for use in relatively dry and impermeable rocks, such as the granite of the western and northeastern United States. The second goal is to demonstrate energy extraction at a rate sufficient to support initially a 10-MW (electrical) generating plant. The third goal is to investigate and develop such modifications of the general method as may be required to make it useful in other geographical locations and geological situations, especially in more permeable rocks.

III. AREA GEOLOGY

The geothermal source demonstration area is located on the Jemez Plateau, which is part of the western arm of the Rocky Mountains extending into northern New Mexico (Fig. 1). Approximately a million years ago, the Valles Caldera was formed when a huge volcano erupted great quantities of ash and then subsided into its own empty magma chamber. The Jemez Plateau was formed as part of an apron of volcanic ash that flowed out of the volcano during the eruptions. Since then, a series of smaller volcanic events has occurred and these are now represented by a number of rhyolite domes along the inner periphery of the caldera. As a result of this relatively recent vulcanism, a large amount of heat is still retained in rocks underlying the entire area within a few kilometers of the surface.

The geology of this region was first described by Renich,[3] and has since been described by Woods and Northrop,[4] Smith et al,[5] Ross et al,[6] and Bailey et al.[7] A regional geologic map was published by Smith et al.[8] Fitzsimmons[9] describes some of the

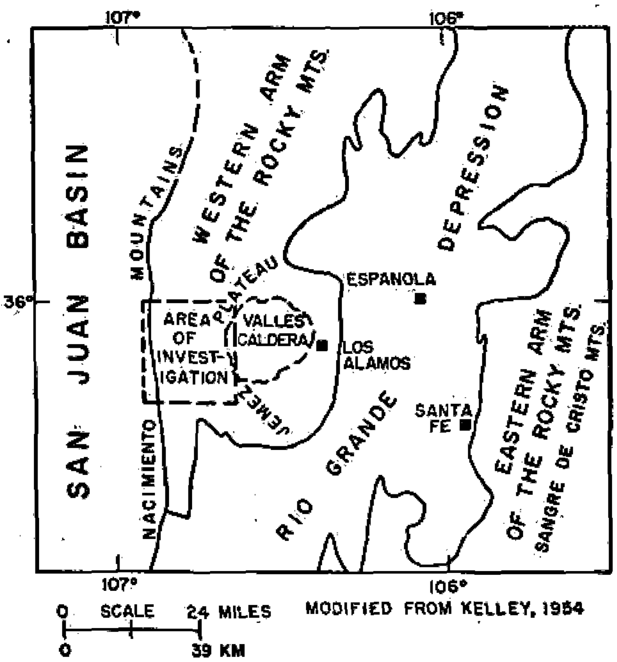


Fig. 1. Major structural features and area of investigation in north-central New Mexico.

Precambrian rocks in the area and West[10] has discussed the geophysics of the Jemez Mountains.

The Los Alamos Scientific Laboratory (LASL) is located on the eastern flank of the Jemez Mountains, about 50 km (30 miles) by road from the demonstration site. Scientists at the Laboratory have for some years been interested in tapping the residual heat of this extinct volcano.

In April 1972, four test holes ranging in depth from 150 m to 230 m (500 to 750 ft) were drilled on the western exterior slope of the caldera. They were cored and cased for geologic investigations and heat flow measurements. A deeper test hole was drilled in May and June of 1972 to obtain additional geological information and temperature data, and to investigate drilling problems in the area. It reached a depth of 785 m (2575 ft), and extended into the Precambrian basement rocks.[11]

The geologic section of Geothermal Test Hole No. 2 has been described in detail by Purtymun et al,[12] and is shown on the summary sheets, Appendix A.

IV. SITE SELECTION

A. Location

On the basis of previous studies, surveys, and field experiments,[13,14] a site on the Jemez Plateau

Fig. 2. Geothermal Source Demonstration Site before erection of drilling rig. The location of GT-2 is on the middle ridge, just to the left of the center.

about 32 km (20 air miles) west of Los Alamos was selected as an appropriate location for development of the first dry hot rock energy experiment. This has been officially identified as the "Fenton Hill Site," or TA-57 (LASL Technical Area 57). It is a gently sloping area on top of a mesa, which was burned over in a forest fire in 1971, so that preparation of the demonstration site involved a minimum of leveling and no destruction of standing timber (Fig. 2). It is immediately adjacent to an all-weather state highway and to power and telephone lines, and is crossed by an existing forest road. Access to the area is convenient, power is immediately available, and communications to and from the site are good.

The Fenton Hill Site is in the Jemez District of the Santa Fe National Forest in Sandoval County, New Mexico. A Memorandum of Understanding was executed between the U. S. Atomic Energy Commission and the Forest Service for use of the site by LASL for drilling and experiments in a deep exploratory hole (GT-2) and, if results from this hole are positive, for the development and operation of a two-hole geothermal energy demonstration system.

The work area for GT-2 is 0.02 km^2 (4.9 acres). Preliminary site plans for the demonstration system involve an additional 0.01 km^2 (2.7 acres). Because of recent geothermal leasing activity in the area, a request was made by the AEC to the Bureau of Land Management that leases not be issued on 0.65 km^2 (160 acres) surrounding a previous exploratory hole (GT-1) in Barley Canyon and about 3.65 km^2 (900 acres) surrounding the GT-2 location, until such time as LASL experimental work at these sites is completed.

B. Environmental Assessment

The Forest Service has agreed that the AEC, as the responsible Federal funding agency, should be responsible for a full assessment of the environmental impact of this project. Such an assessment has been made, and it is the conclusion of the AEC that an environmental impact statement is not required for activities now planned at the Fenton Hill Site, including the drilling of GT-2, the two proposed energy experiment holes, and the development and experimental operation of a water-circulation loop. If, however, within about 5 years, experiments at this site are judged to be sufficiently successful to justify construction of a demonstration electrical generating plant, it is anticipated that this follow-on program would then require an environmental impact statement.

An Environmental Analysis Feasibility Report was prepared by the Forest Service covering the surface impacts of the Dry Geothermal Source Demonstration Project, and has been approved by the Acting Supervisor of the Santa Fe National Forest. An Environmental Analyses Detailed Coordination Report is therefore now being prepared by the Forest Service covering the several phases of the project scheduled to follow the drilling and experiments in GT-2. Subject to agreement concerning disposal of precipitates from the demonstration system and to any further stipulations that may be included in that report, the Forest Supervisor has now approved proceeding with all phases of the present project at Fenton Hill (TA-57).

V. PROJECT PLANNING

A detailed plan of the proposed drilling program for GT-2 was prepared in December 1973. The revised version of this plan, dated March 20, 1974, is included as Appendix B of this report.

The plan outlined the drilling and testing schedule (based on information gained from GT-1),

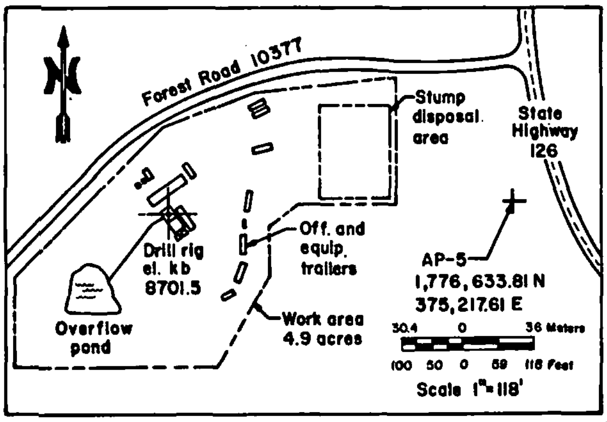


Fig. 3. Site plan, Dry Geothermal Source Demonstration Project.

and listed the various experiments and measurements that were considered essential to the success of the demonstration.

Because of unforeseen events, some parts of the plan were not accomplished. These changed aspects of the work will be discussed in the concluding section of this report.

VI. SITE PREPARATION

A contract for the preparation of the GT-2 drilling site (TA-57, Fenton Hill Site) was let to Law Construction Company of Espanola, New Mexico on December 20, 1973. Work in the form of snow, brush, and stump removal began on January 10, 1974.

The site plan for the project is shown in Fig. 3. In general, the site-preparation work included leveling and grading of the drilling site, excavation and timbering of a drilling cellar, excavation and embankment work for a 570 m^3 (150,000 gal) settling pond, construction of an electrical substation pad, and erection of a secondary electrical distribution system consisting of 120 m (400 ft) of aerial line and two service pedestals.

By March 1, the contract work had been completed, except for regrading and reseeding the site when work on GT-2 is finished.

During this time, arrangements were made with the Jemez Mountains Electric Cooperative for power at the site. Telephone lines were installed and an emergency radio communication system was established.

VII. DRILLING HISTORY

A. Contractual Agreements

More than 30 separate contracts were let to cover drilling and associated work at the Fenton Hill Site. The major contracts are listed and described below.

1. Drilling Contract

a. Contractor Selection. An independent estimate of drilling costs for GT-2 was requested from and prepared by Fenix and Scission, Inc., Las Vegas, Nevada. Early in January, bids were solicited from drilling contractors on the specifications in Appendix C. Three bids were received, of which one was for oversize equipment and was extremely high, and a second was eventually withdrawn because of excessively long delays in actually awarding the contract. The drilling contract was finally awarded on February 6 to the only remaining qualified bidder, Calvert Western Exploration Company of Tulsa, OK.

The specifications of Drilling Rig. No. 24, which Calvert Western proposed to use, are listed in Appendix D.

b. Contract Items. The original contract with Calvert Western contained four major items: mobilization; hourly rates for work using drill pipe, without drill pipe, and standby-secured; reimbursable (seller acquired) items and services; and demobilization.

This contract provided for not more than 57 days of drilling and 30 days of post-drilling services. Subsequent modifications to the original contract extended the length of the contract to 176 days, and provided increases for reimbursable items and services.

c. Third-Party Contracts. Item III. C. of the drilling contract for reimbursable (seller acquired) items and services provided the basis for obtaining equipment and services under a "third-party" agreement. Typical services which were furnished to the drilling contractor under this item included the following: cementing, fishing, logging, welding, casing setting, trash removal, bits, reamers, stabilizers, collars, packers, retainers, diesel fuel, butane, water, and diamond core bits.

2. Mud Services

A contract for drilling-mud services was let to Baroid Division, Natural Lead Industries, Inc., Farmington, New Mexico. The original contract provided for a mud-drilling program to be furnished by Baroid for drilling approximately

305 m (1000 ft) through and below the Permian red beds. Included were 18 days of continuous mud engineering services, consisting of a mud engineer and a laboratory-equipped trailer on location, a drill-pipe-corrosion monitoring service, drill-fluid testing, and recommendations for treatment. All necessary mud-drilling materials, such as mud, chemical additives, and lost-circulation materials were to be furnished according to the effective customer price list.

Modifications to the original contract changed the length of the contract to approximately 33 days.

3. Compressed-Air Services. A contract for compressed-air services was let to I-R Compression Services, Ingersoll-Rand Company, Denver, Colorado. The original contract provided for the rental of a minimum of three primary air compressors, a booster pump, a mist pump, and the services of an engineer and two operators for approximately 47 days for use in drilling from 792 m (2600 ft) to a minimum of 1372 m (4500 ft).

The specifications required heavy-duty compressors, each to provide pressures up to 2.1 MPa (300 psig) in continuous service and 1.1 m^3/s (2400 SCFM) at an elevation of 2650 m (8700 ft). The booster pump also was required to handle 1.1 m^3/s at an inlet pressure of 1-1.6 MPa (145-235 psi), and to be capable of boosting discharge pressures up to 10 MPa (1500 psig) continuously. The mist pump was specified to be 0.001 m^3/s (16 gpm) capacity at 10 MPa (1500 psi). The necessary chemicals and additives were on consignment basis. Modifications to the contract changed the length of time to approximately 86 days.

4. Road and Site Maintenance. A contract was let to C.J.C. Inc., General Contractors, Jemez Springs, New Mexico, to provide necessary road maintenance, snow removal, site modifications and earthwork (necessary to adapt the previously prepared site to the selected drilling contractor's equipment), drainage and other general support operations not provided by the drilling contract.

Included in this work was raising the height of the dam of the original settling pond and riprapping a small overflow spillway, digging two additional settling ponds, placing gravel on the work areas around the drilling rig, burying electrical

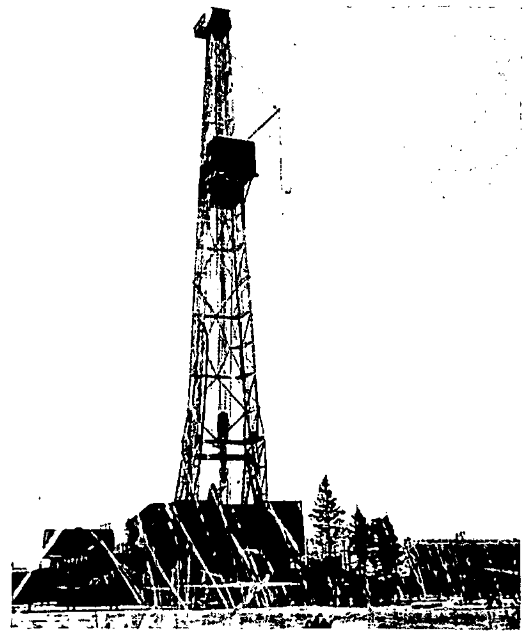


Fig. 4. Drilling rig on location at the Fenton Hill Site.

cables and road drainage culverts, and leveling additional instrumentation trailer areas.

B. Drilling Progress

1. Mobilization. On February 9, Calvert Western moved Drilling Rig. No. 24 onto the location at Fenton Hill and began erection the next day. By February 16, the drilling rig was in operational condition (Fig. 4).

The contractor employed four drilling crews, each consisting of a driller, a derrickman, and three floormen. Drilling progressed 7 days/wk, 24 h/day. Each crew worked an 8-h shift for 6 days, then had 2 days off and came back to work on the shift preceding the one that they had previously worked. The superintendent, or tool-pusher, had a trailer at the drill site and was available on a 24-h basis.

The elevation of the top of the Kelly bushing was 2652 m (8701.5 ft) above mean sea level, and all depths were measured from this point.

2. Surface Conductor Casing. From February 17 through 19, the 0.63-m-diam (25-in.) hole for the surface casing was drilled to a depth of 18 m (60 ft). The 0.51-m-diam (20-in.) casing was then set in place and concreted.

3. Volcanic Rock. At 9:00 a.m. on February 20, drilling began in the volcanic tuff rock below the surface pipe, using 31-cm (12-1/4-in.) tricone rock

bits. The average drilling rate was 7 to 8 m/h (20 to 25 ft/h). Minor lost-circulation problems were encountered at the 27- and 37-m depths (90- and 120-ft), but these presented no serious difficulties. The basic drilling mud consisted of a mixture of Aquagel and Benex to produce a weight of about 1 kg/liter (9 to 9.5 lb /gal) and a viscosity of 40 to 55 s.*

4. Sedimentary Rocks. Below the tuff, drilling progressed in the Abo Formation (Permian red beds) at the rate of 8 to 9 m/h (25 to 30 ft/h), and in the Madera Formation (Pennsylvanian shales and limestones) at approximately 2 m/h (6 to 8 ft/h). The drilling rate varied considerably in the Abo Formation, from a maximum rate of 18 m/h (60 ft/h) to a minimum of 3 m/h (10 ft/h). Penetration rates in the Madera Formation were more uniform, but varied more widely in the underlying Sandia Formation.

On February 28, at a depth of 584 m (1916 ft), all circulation of the drilling fluid was lost in a highly permeable zone in the Madera Limestone. Several lost-circulation additions were tried, followed by two unsuccessful cementing attempts. After fighting the lost-circulation problems for a week, and with the condition of the hole deteriorating rapidly from squeezing clay layers and caving shale beds, it was decided to case the hole. On March 9, the hole was reamed with a 45-cm-diam (17-1/2-in.) hole-opening bit to a depth of 489 m (1605 ft). A string of 34-cm-diam (13-3/8-in.) casing was set to 488 m (1600 ft) in a competent limestone bed and cemented into place (Fig. 5).

Redrilling through the cement began on March 17, using water as the drilling fluid. At a depth of 576 m (1889 ft), circulation was again lost and a change-over to air drilling was made. Air drilling continued until March 25, with many problems from balling of the clay layers, sticking of the drill pipe and caving of the formation. Soap, mud, and Gel-Foam additions were used to create emulsions to clean and stabilize the hole while drilling continued to 680 m (2230 ft). However, water inflow and caving remained serious problems. Between March 26 and 28, 2200 sacks of cement were injected into the the hole in eight separate cementing operations. At

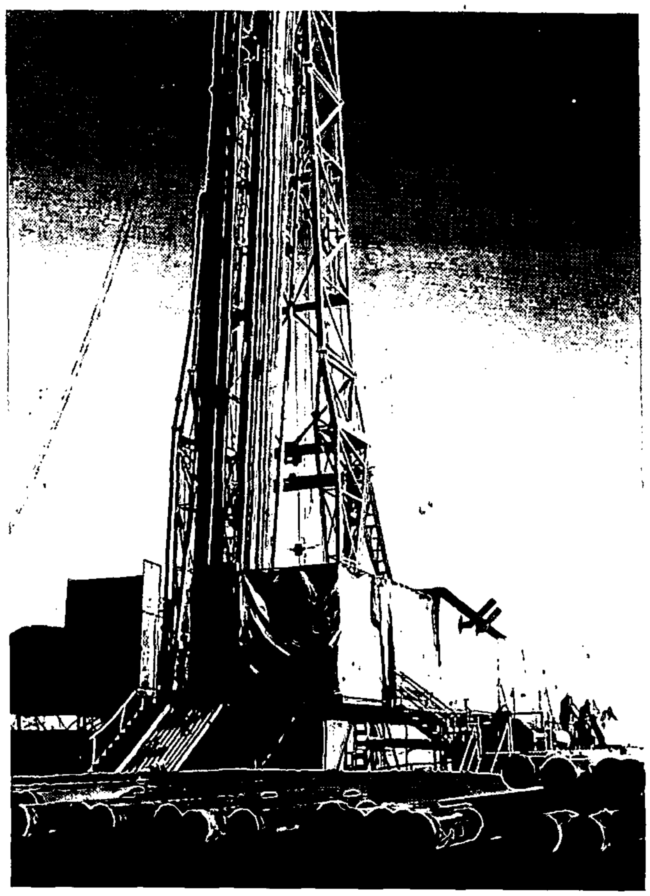


Fig. 5. Prior to installation, racks of 34-cm-diam (13-3/8-in.-diam) casing are stored in front of the drill rig.

the finish of the cementing, the top of the cement stood at 485 m (1590 ft)--approximately 5 m (15 ft) up in the casing. Air drilling was resumed through the cement plugs. The Precambrian granite surface was reached at a depth of 732 m (2404 ft) on March 30, but caving of the overlying sediments continued to present serious problems. The hole was cemented in four increments from the 751-m depth (2463-ft) to about the 614-m depth (2105-ft). Drilling was resumed with air, with continuous caving of the sedimentary formations above the granite. The hole was finally extended to 773 m (2535 ft)--about 40 m (130 ft) into the granite. At this point, caving was so serious that casing was inserted as soon as possible in order to save the hole. A 27.3-cm-diam (10-3/4-in.) casing was set from the surface to 773 m (2535 ft) and cemented into place on April 6.

Throughout the sedimentary beds, drill cuttings were obtained at 3-m (10-ft) intervals, and were used

*All drilling mud viscosity values used in this report are American Petroleum Institute funnel viscosity units.

extensively to interpret the lithology of the geologic section.

Maximum hole deviation in the sedimentary beds was 1-3/4 degrees from the vertical.

5. Granitic Basement. When the casing cement had set, the hole was cleaned and, returning to air drilling, was extended 3.7 m (12 ft) into the pinkish-gray granite below the casing shoe, using a 24.4-cm-diam (9-5/8-in.) full-face tricone bit. The hole was pressure tested with air to 1.9 MPa (280 psi) and appeared to be tight.

Drilling continued with air until April 23, when, at a depth of 1080 m (3542 ft), the amount of water being blown from the hole threatened to overflow the settling pond. Because the agreement with the Forest Service included a commitment to not let any drilling fluid escape, efforts were made to reduce the inflow of water to the hole.

A series of logging tests indicated that there was no evidence of damage or separation of the casing itself, but that the water flow was probably entering the hole around the bottom of the casing. Prior to cementing the hole to seal off the water, a wireline plug was set at a depth of 786 m (2580 ft) and a removable packer at 732 m (2400 ft). On April 25, 300 sacks of cement were injected into the space between the packers with an estimated 200 sacks of that amount being squeezed out into the formation. The cement plug was then drilled out, but before the bottom packer was broached, increasing water flows halted drilling. An additional 300 sacks of cement were injected above the lower packer on April 29.

After drilling out the cement plug, the hole again filled with water. As the water level was about the same depth as the lost-circulation zone in the Madera Formation, it was speculated that the water-bearing zone communicated with an aquifer above the granite. Testing with a Lynes packer revealed that the hole accepted water across a wide interval below 960 m (3150 ft). Air circulation could not be maintained when the drill bit was below 823 m (2700 ft). On May 4, two injections of 150 sacks each of cement filled the hole to a depth of 951 m (3119 ft). When the plug was drilled out to the bottom depth of 1084 m (3556 ft), the hole again filled with water.

At that point, it was decided to drill ahead with drilling fluid through the water-bearing zone, without returns if necessary. A pump was installed in the reserve pit to supply additional water to the hole and, at the same time, to draw down the water level in the pit. Drilling in the granite progressed to 1117 m (3666 ft), at which time a pressure test was attempted with a Lynes packer set at 1102 m (3615 ft). However, the packer could not be made to hold. Actually, it had only partially inflated, had become disengaged from the drill pipe, slipped to the bottom of the hole, and was required to be fished out. Comprehensive temperature logging indicated that the hole was probably tight below 1097 m (3600 ft), as there was no inflow of water below that depth.

It was planned to set a bridge plug at 1029 m (3375 ft) and to perform a squeeze-cement operation from there to the bottom of the hole. The bridge plug leaked, was removed, and the cementing was done through open-ended pipe at 1103 m (3619 ft). A batch of 300 sacks of cement with 3% calcium chloride, formulated to set up in 1 h 45 min at 26°C, was injected. Actual set time was 19 min, and 29 stands of drill pipe were left full of hardened cement. The pipe was sent to Farmington, New Mexico, to be drilled out and additional pipe was rented.

Drilling was resumed with fluid and continued to 1136 m (3728 ft). Additional temperature measurements indicated that water was still entering the hole at about 1097 m (3600 ft); caliper logs showed an enlarged section of hole between 1082 and 1097 m (3550 and 3600 ft), with an additional enlargement at 981 m (3220 ft). On May 15, open-ended drill pipe was set at 1122 m (3680 ft) and 150 sacks of cement were injected. The cement was formulated to give 1 h 37 min of pumping time at 110°C. Within 20 min after the cement was mixed, it had been completely placed. The drill pipe was started out of the hole immediately, but it became stuck as it was first being pulled. All efforts to rotate and lift the pipe failed, and it was cemented in the hole.

Preparations began promptly to free the cemented pipe. The cement within the pipe was found to be at a depth of 985 m (3232 ft), and was drilled out on May 18 with a 9-cm-diam (3-1/2-in.) bit. A stuck-pipe indicator was used to locate the point at which the pipe was cemented in externally. Attempts to loosen the first two joints above this point, with

Fig. 6. Washover shoe, 20-cm-diam (8-in.) i.d., dressed with crushed boron carbide, used in drilling out the cemented-in drill pipe.

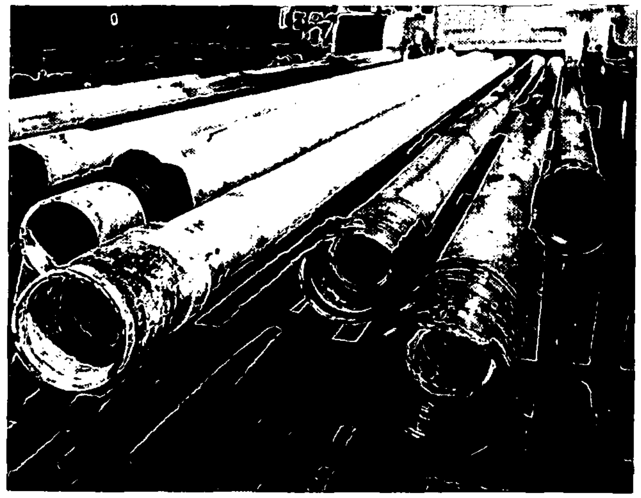


Fig. 7. Box ends of drill pipe which were milled off during the washover operations.

a back off tool and Primacord string shots, were unsuccessful. The third shot, on May 19, at the third joint above the indicated cement level, was successful, and all but 101 m (330 ft) of the stuck drill pipe was removed from the hole.

Cement in the annulus, between the drill pipe and the borehole wall, was encountered at 1084 m (3556 ft). Drilling of this cement, using washover pipe and a variety of mill-tooth bits, including diamonds, continued until May 28, when all of the cemented drill pipe was removed (Fig. 6). A number of pieces of drill pipe had been pushed against the side of the hole, apparently by differential sticking. This condition required milling off about half the wall thickness of the pipe section for its entire length (Fig. 7).

Drilling in the granite then continued at the rate of 1.7 m/h (5 to 6 ft/h) with water still coming into the hole at the rate of 0.004 m^3/s (60 to 70 gal/min). As the depth increased, it became more difficult to blow the water from the hole. On June 2, the air compressors were shut down and a conversion to water drilling was made. Records kept on the drilling performance of two successive Smith 9JS bit runs revealed a small, but distinct, advantage in water drilling over air drilling on the basis of both drill rate and bit wear.

As a result of this comparison, the Ingersoll-Rand contract for compressed air was terminated on June 4, and the compressor equipment was subsequently removed from the site. Drilling with fluid continued with the fracture zones accepting water under hydrostatic head. On June 10, small additions of bentonite and lost-circulation materials to the drilling fluid were begun in an effort to seal off these water loss zones and to aid in removing the cuttings. The average mud viscosity ranged from 30 to 35 s, with a weight of 1.0 kg/liter (8.6 lb /gal). The loss of drilling water was not completely checked, but it gradually decreased from 1.7 m^3/h (440 gal/h) to about 0.6 m^3/h (150 gal/h).

In the lower section of the hole, with drilling progressing at a steady rate, a fairly uniform picture of bit life began to emerge. To obtain maximum information on the characteristics of the granitic rock, numerous core runs and temperature measurements were interspersed in the drilling schedule at selected intervals. A procedure was developed to standardize the drilling-logging-coring sequence of operations, which will be described in subsequent sections of this report.

A preliminary terminal depth of 1935 m (6350 ft) was reached at 10:25 a.m., July 12. The last drilling had been a 2-m (6-ft) core run, which yielded only about 15% recovery. During the post-drilling diagnostic logging, a partial obstruction was encountered in the hole which required redrilling. Because the previous core recovery had been poor, and with the bit on bottom to clean the hole, an additional 2-m (6-ft) core run was made to a total first-phase depth of 1937 m (6356 ft).

The hole deviation at this depth was 4-1/2 degrees from the vertical.

VIII. CASING

A. Conductor Casing

The conductor casing consisted of 20 m (65 ft) of 0.51-m-o.d. (20-in.) line pipe. Eight centralizing fins were welded on the exterior, and a 0.51-m-o.d. (20-in.) nominal pipe flange was welded on the upper end to connect to the blowout preventer (Fig. 8). The backfill concrete was furnished by a local ready-mix supplier, and consisted of 3.8 m^3 (5 yd^3) of 34.5-MPa (5000-psi) strength concrete containing 9.5-mm (3/8-in.) aggregate.

B. Surface Casing

The surface string of casing was included in the specifications to be placed only as required. As drilling progressed into the sedimentary beds, it became apparent that this intermediate casing was necessary to keep the hole open. The diagnostic logs indicated a thick bed of solid limestone at 488-m (1600-ft) depth. The hole diameter at this depth was very close to bit gauge.

On March 15, the intermediate surface casing was set at 488 m (1600 ft). The casing was 34 cm o.d. (13-3/8 in.), 81 kg/m (54.5 lb /ft), Type J-55, eight-RD thread. A Baker cement shoe was installed at the bottom of the casing, and a Baker float collar at 479.5 m (1573 ft).

Prior to insertion of the casing, two drums of Baroid Torq-Trim were mixed with the drilling mud to increase the lubricity of the borehole walls.

Cementing of the casing was performed by the Farmington, New Mexico, station of Dowell, a division of Dow Chemical Company. The cementing operation began at 6:00 a.m., March 16, by pumping 1.6 m^3 (10 bbl) of water down the casing ahead of the cement, followed by 54 m^3 (341 bbl) of cement slurry at a pressure of 1.7 MPa (250 psi). A rubber plug was run in the casing after the cement, which was displaced from the casing by pumping in 39 m^3 (243 bbl) of water. When the cement failed to circulate to the surface after this displacement effort, 8.7 m^3 (55 bbl) of additional cement slurry were pumped down the annulus by means of a 3.2-cm-diam (1-1/4-in.) pipe placed 122 m (400 ft) down the outside of the casing. Approximately 1.6 m^3 (10 bbl) of slurry were circulated to the surface by this means.

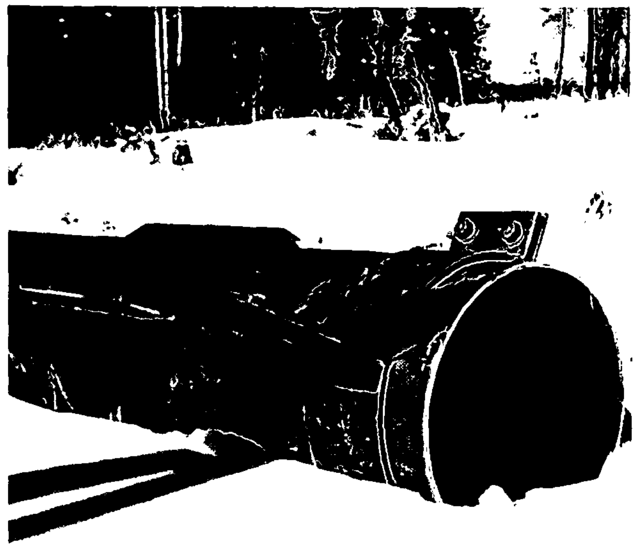


Fig. 8. Conductor casing with centralizing fins.

The total quantities of cement and admixtures are listed below:

Cement, Ideal Class A	17.7 m^3	626 ft^3
Dowell Litepoz 3	9.2 m^3	324 ft^3
Bentonite (12.4%)	15.3 m^3	540 ft^3
Bentonite (2%)	26.9 m^3	950 ft^3
Dowell D-79, chemical extender	381 kg	840 lb
Dowell D-33, $CaCl_2$	277 kg	500 lb

C. Deep Casing

The bottom of the deep casing string was set at 773 m (2535 ft); the top extended to the surface. The casing was 27.3 cm o.d. (10-3/4 in.), 67.7 kg/m (45.5 lb /ft), Type K-55, with both Hydril and buttress threads. A Baker cement shoe was installed at the bottom of the casing, and a Baker float collar at 733 m (2404 ft). Both strings of casing were installed by San Juan Casing Service, Inc., of Farmington, New Mexico.

Cementing of the deep casing string was performed by Dowell. The cementing operation began at 5:58 p.m., April 6, by pumping 40 m^3 (250 bbl) of water into the casing, followed by 9 m^3 (57 bbl) of cement slurry at a pressure of 3.4 MPa (500 psi). A rubber plug was run down the casing after the cement, displaced by 56 m^3 (350 bbl) of water. An estimated 10-m-high column (33-ft) of cement slurry was left standing in the casing.

The total quantities of cement and mixtures are listed as follows.

Cement, Ideal Class A	5.9 m^3	210 ft^3
Cement, silica sand	3130 kg	6900 lb
Dowell D13R, calcium lignosulfonate	45 kg	99 lb

IX. CEMENTING

Cementing operations to stabilize the hole and/or reduce water inflows are described by dates of their occurrence. The separate quantities of cement and admixtures used in each injection are shown on the summary sheets in Appendix A.

Generally, all cementing fluid (slurry) injections were accomplished under hydrostatic pressure (except as noted) and were preceded and followed by approximately 2 m^3 (10 to 15 bbl) of water.

A. March 3, 1974

1. Contractor. Halliburton Oil Well Cementing Company, Farmington, New Mexico.

2. Depth. 421 to 448 m (1380 to 1470 ft), through open-ended drill pipe.

3. Total Slurry Volume. 7.9 m^3 (280 ft^3).

B. March 7, 1974

1. Contractor. Halliburton Oil Well Cementing Company.

2. Depth. 411 to 549 m (1350 to 1800 ft), through open-ended drill pipe.

3. Total Slurry Volume. 8.5 m^3 (300 ft^3).

C. March 25-27, 1974

1. Contractor. Dowell Division of Dow Chemical, Farmington, New Mexico.

2. Depth. Eight successive cementing sequences from 485 to 680 m (1590 to 2230 ft), through open-ended drill pipe.

3. Total Slurry Volume. 100 m^3 (3520 ft^3).

D. April 3, 1974

1. Contractor. Dowell Division.

2. Depth. Four successive cementing sequences from 614 to 721 m (2015 to 2366 ft), through open-ended drill pipe.

3. Total Slurry Volume. 36 m^3 (1280 ft^3).

E. April 25, 1974

1. Contractor. Dowell Division.

2. Depth. The hole had been drilled to 1080 m (3542 ft); a wireline plug was set at 786 m (2580 ft) and a removable packer at 732 m (2400 ft). The bottom plug leaked, weak cement was redrilled to a depth of about 985 m (3230 ft).

3. Total Slurry Volume. 10 m^3 (354 ft^3).

4. Pressure. 6.9 MPa (1000 psi).

F. April 28, 1974

1. Contractor. Dowell Division.

2. Depth. Before drilling out the lower plug that was set in the previous cementing operation, a drillable upper retainer was set at 746 m (2448 ft) and the interval to 786 m (2580 ft) was recemented.

3. Total Slurry Volume. 10 m^3 (354 ft^3).

4. Pressure. 3.4 MPa (500 psi).

G. May 4, 1974

1. Contractor. Dowell Division.

2. Depth. Two successive cementing sequences from 951 to 1084 m (3119 to 3556 ft), through open-ended drill pipe.

3. Total Slurry Volume. 11.9 m^3 (420 ft^3).

H. May 9, 1974

1. Contractor. Dowell Division.

2. Depth. Bottom of hole at 1113 m (3650 ft); open-ended drill pipe at 1103 m (3619 ft); cement set up before being displaced from drill pipe. Cemented interval was approximately 9 m (30 ft^3).

3. Total Slurry Volume. 12.7 m^3 (450 ft).

I. May 15, 1974

1. Contractor. Dowell Division.

2. Depth. Bottom of hole at 1136 m (3727 ft); open-ended drill pipe at 1122 m (3680 ft); pipe became stuck in the hole before it could be pulled. Cemented interval was 1084 to 1136 m (3556 to 3727 ft).

3. Total Slurry Volume. 6.8 m^3 (240 ft^3).

J. Investigation of Cementing Operations of May 9 and 15

A comprehensive investigation was conducted to determine the cause of the difficulties incurred during the cementing operations of May 9 and 15. Tests performed at Dowell Laboratories in Tulsa, Oklahoma indicated considerable difference in stiffening time between materials actually used in the field on May 9 and laboratory samples of similar materials received from manufacturers. The Tulsa office had recommended that no calcium chloride be used in that mix; however, it was included in the field design. In this instance, a laboratory test of the mix prior to pumping would have foretold the reaction that was obtained and would have averted the drill pipe being filled with hardened cement.

Regarding the cementing operation of May 15, it first appeared that contamination of the cement from the mud-pit water or from dirty drill pipe might have caused a premature set. It now seems more likely that the pipe first became mechanically stuck through dehydration of the cement or because of differential sticking at the water-loss zone between 1082 and 1097 m (3550 and 3600 ft). The cement slurry, flowing down the drill pipe, up the annulus, and out into the formation at this zone, either (1) formed a filter pack, through which the water was squeezed, leaving the cement behind in a compact, semihard condition around the drill pipe; or (2) pushed the pipe against the side of the hole with enough force to prevent it from being rotated or withdrawn.

A section of bent drill pipe which was later removed from the hole at about the depth of the water-bearing zone, and the presence of cement that drilled as if it might have been dehydrated, are indications that these events could have occurred.

X. DRILLING MEDIA

A. Mud

The Permian red beds (known as the Abo Formation in New Mexico) underly much of the Southwest, and are renowned for causing severe drilling problems.

The development of a suitable mud program to facilitate drilling of future geothermal holes through the Abo Formation into the Pennsylvanian-age limestones was planned as an integral part of the studies designed for GT-2 (see Appendix B).

The services of Baroid began on February 15, 1974. A laboratory trailer was installed at the drill site and continuous supervision of the mud program was provided by two representatives who alternated tours. The initial drilling fluid mix was a low-solids mud, consisting of a ratio of five sacks of Aquagel to one sack of Benex (Fig. 9). This mix had a solids content of 3% by volume, a weight of 1 kg/liter (9 lb /gal) and a viscosity of approximately 40 s.

When the lost-circulation zones were encountered at the 27- and 37-m depths in the tuff (90- and 120-ft), the solids content was raised to 6%, by adding one sack of Cellex to each sack of Benex. Several "pills" of lost-circulation materials (Fibertex, Gel-Flake, and Plug-git) were injected before circulation was regained.

Fig. 9. Mixing drilling mud in the drilling rig mud tanks. Mud testing trailer is seen in the background.

Drilling in the sedimentary beds continued, using a mixture of five sacks of Aquagel to one of Cellex, plus 23 kg (50 lb) of caustic soda each shift. The solids content varied from 8 to 10%; weight was 1 kg/liter (9.5 lb /gal) with an average viscosity of 54 s. The Abo Formation was penetrated successfully and the hole seemed to remain quite stable. At a depth of 584 m (1916 ft), nearly 213 m (700 ft) into the Madera Limestone, all circulation was lost. At that time, the mud volume in the hole was calculated to be 48 m^3 (300 bbl), with 95 m^3 (600 bbl) in the mud pits. The initial mud loss to the formation was approximately 32 m^3 (200 bbl). Lost-circulation materials, up to 30% by volume of the mud mix, were added, but the formation took another 40 m^3 (250 bbl) without any return.

A high-filtrate plug consisting of 200 sacks of Diacel D was mixed, pumped down the hole, and displaced with 8 m^3 (50 bbl) of mud containing 30% lost-circulation materials.

On March 1 and 2, two high-filtrate plugs, each consisting of 100 sacks of Diacel D, were mixed and pumped down the hole, displaced with 8 m^3 (50 bbl) of mud containing 30% lost-circulation materials. Bridges and caving hole conditions began to appear higher in the hole in the Abo Formation, giving considerable trouble in drilling back down to bottom. Two cementing attempts were largely unsuccessful. On March 6, another 150-sack plug of Diacel D was placed in the hole, followed by more cement.

During the hole-opening operation to install the intermediate casing, viscosity was maintained at 50 to 60 s, with 15% to 20% lost-circulation materials. Cottonseed hulls, Fibertex and Plug-git were used in a mud mix consisting of six sacks of Aquagel to one sack of Cellex.

On April 6, during the setting of the deep casing string, 48 m^3 (300 bbl) of mud with a viscosity of 270 s, and 0.5 m^3 (3 bbl) of Torq-Trim were spotted in the hole.

B. Foam

After setting the intermediate casing, it was planned to redrill through the cement with water until circulation was lost, then convert to air drilling. This was done, and air drilling continued using mist and soap to a depth of 657 m (2156 ft). At that point, very few cuttings were being returned and the hole was frequently loading up with water.

On March 23, a mixture of Baroid Gel-Foam was tried. The concept of a foam drilling medium theoretically combines the advantages of mud drilling with those of air drilling. It is particularly advantageous in zones where there is excess water influx into the borehole, or where the nature of the formation material, such as sticking clays, makes the use of compressed air inefficient in keeping the hole clean.

The foam was mixed to the following proportions.

Aquagel	34 kg/m^3	(12 lb /bbl)
Soda ash	2.8 kg/m^3	(1 lb/bbl)
Cellex	2.1 kg/m^3	(0.75 lb /bbl)
Foaming agent		1% by volume

Use of the foam appeared to be cleaning the hole and maintaining sidewall stability, when all circulation was lost as the bit neared bottom. A plug of 1361 kg (3000 lb) of cottonseed and walnut hulls was pumped down the hole, but returns were not established. The hulls clogged the mist pump and temporarily made the further use of foam impossible.

On March 31, after the granite surface had been reached (although continuous caving from above still threatened the hole), foam was again tried. Aquagel, soda ash and Cellex were combined in the mud-pit tanks and transferred to the mist tank after being strained through burlap to remove lost-circulation materials. The foaming agent was added at the mist tank. Drilling with foam was terminated on April 3, when the borehole was cemented. Foam drilling provided good results under extremely adverse drilling conditions.

C. Air

As outlined in the plan for experiments and measurements in GT-2 (Appendix B), the circulation medium for all drilling in granitic rock was to have been compressed air. It was felt that compressed air would be superior to fluids for these reasons:

(1) Air drilling would not decrease the natural temperature of the rock as much as fluid, and the downhole temperature measurements would be much more accurate;

(2) Drilling in granite is usually faster with air; and

(3) Water was not readily available and had to be hauled to the site.

Air drilling actually began at a depth of 576 m (1889 ft) when water circulation was lost in the Madera Limestone while redrilling a previously cemented zone. Instead of fighting to keep circulation of the drilling fluid, it was decided to drill ahead with air. This would permit downhole progress to be made without the need for returns and without the cost of water and mud.

A blooie box with internal baffles and water-spray scrubbers was installed on the flow line to catch the cuttings (Fig. 10). The box was only partially successful. The water jets became frozen shut during cold weather, the mud-pit water that was pumped to the box contained enough lost-circulation materials to plug the jets, and the cuttings continually built up in front of the box, which caused the box itself to become clogged with cuttings. With constant cleaning and maintenance, the box operated satisfactorily.

Drilling with air continued through the sedimentary beds with various additions of soap, mud, and foam. After the deep casing string was set, it was hoped that air drilling would proceed without difficulty. However, as the depth increased, it became increasingly difficult to blow the water out of the hole. The air-circulation medium was satisfactory as long as steady drilling was in progress.

Fig. 10. Blooie box is shown in position at the end of the flow line between the settling ponds.

When drilling was temporarily halted to make a connection, the hole filled with so much water that the compressors had difficulty unloading the water from the hole.

The cuttings that were returned up the hole during the air-drilling operations were very fine. It was suspected that the true amount of quartz that was actually in the rock was not being represented in the cuttings. This premise later proved to be correct. The quartz crystals, being extremely brittle, were crushed into fine powder by the drilling impact and were either blown away as dust or didn't settle out with the rest of the cuttings when the blooie box was operating.

At a depth of 1084 m (3556 ft), with much water coming into the hole, a temporary conversion to water drilling was made to drill through the water-bearing zones.

Air drilling began again on May 28, 1974, at a depth of 1136 m (3728 ft) after the cemented-in drill pipe had been removed. At that time, water was being blown from the hole at the rate of approximately 0.3 m^3/min (80 gal/min), with an air pressure varying from 1.24 to 1.52 MPa (180 psi to 220 psi). On June 2, due to increasing water inflow, air drilling was halted, this time permanently. The Ingersoll-Rand contract was terminated on June 4, and the compressor equipment removed from the site.

D. Water

Although water had been used for redrill in the upper parts of the hole and for drilling through water-bearing zones until they could be cemented off, little consideration was given to steady water drilling until a test of its drilling performance relative to air was made on June 2.

Two successive runs with Smith 9JS bits provided this comparison.

	Drilling Medium	
	Air	Water
Footage	60.7 m (199 ft)	78.3 m (257 ft)
Time	39 h	42 h
Bit wear	0.64 cm (1/4 in.)	0.32 cm (1/8 in.)
Reamer wear	0.32 cm (1/8 in.)	0.16 cm (1/16 in.) & none
Rate	1.6 m/h (5.1 ft/h)	1.9 m/h (6.1 ft/h)

As a result, a permanent conversion to water drilling was made. At this time, as well as in previous instances when water was used, a pump was installed at the settling pond and water was pumped from there to the rig mud pits. Operations continued in this manner until June 10, when pumping from the settling pond was halted and the use of fresh water entirely for drilling began.

The fracture zones in the granite were accepting water at this time and, although the fraction of return water was large, very few cuttings were being returned. It was thought that the cuttings were being carried out into the formation. Not only did this result in a lack of information about the rock being drilled, but it was feared that the intrusion of cuttings into the formation might adversely affect future experiments.

In view of this, small quantities of bentonite and lost-circulation materials were added to the fresh drilling water to seal off the water-loss zones at the borehole and to help carry the cuttings up. (Testing had indicated that water in the settling pond was too contaminated to be used for even a small-scale mud program.) Daily trips were made to the site by Baroid personnel to test the drilling fluid and make recommendations. On June 11, small amounts of fine-grained MicaTex were added; on June 18 the addition of Carbonox and caustic soda was begun.

The average viscosity of the drilling fluid for the final stages of drilling was 30 to 35 s, with a weight of 1 kg/liter (8.6 lb /gal).

With the use of water, drilling progressed much faster and with fewer problems than with air. The water pumps on the drilling rig provided a continuous supply of drilling fluid to the hole, whereas with air drilling, minor mechanical problems with the compressors occurred frequently. Also, oxidation of the drill bits and pipe was considerably less with water drilling.

XI. DRILL BIT PERFORMANCE

A. Volcanic Rock

After the conductor casing has been cemented in place, drilling commenced with a Smith Tool Company 31.1-cm-diam (12-1/4-in.), Type 3JS, steel-toothed tricone rock bit. The remaining 122 m (400 ft) of volcanic tuff rock was drilled rather easily in about 30 h.

B. Sedimentary Rock

Drill bits from three manufacturers were used in the sedimentary beds to drill the initial 31.1-cm-diam (12-1/4-in.) hole. The drilled footages and hours of use of each bit are recorded on the Drill Bit Record Charts in Appendix E.

Two Smith Tool Company bits each drilled nearly 183 m (600 ft) of hole in a single run, while the Hughes Tool Company and Security/Dresser bits each drilled less than half of that amount. For the hole-opening phase of the drilling, Smith 44.5-cm-diam (17-1/2-in.) bits were used.

The footage records of the various bits are, to a degree, misleading because so much time was spent in redrilling and washing through caving and squeezing layers of shale and clay.

C. Granitic Rocks

The final casing size of 27.3 cm diam (10-3/4 in.) dictated a maximum bit size of 24.4 cm diam (9-5/8 in.). Smith Tool Company and Hughes Tool Company were the only suppliers who could furnish the bits in the time required. Actually, Hughes Tool Company supplied only one bit, which was considered to be too soft for crystalline rock drilling and was subsequently used only for reaming. Except for the bits used to drill cement and bridge plugs, and for coring, the only bits used to drill the crystaline rock were the Smith 9JS bits.

Because of the difficulty encountered in drilling with air, long runs with a single bit were not common practice. The longest run with a bit using air as the drilling medium terminated at a depth of 866 m (2842 ft), after drilling 72 m (237 ft) in 38 h. Beginning at a depth of 1162 m (3814 ft), records of the drilled footage, the time in use and the bit wear were kept for two successive Smith 9JS bits. These results are shown in Table I. As a result of the distinct advantage in footage and wear that was obtained with water drilling, a permanent conversion to water drilling was made.

TABLE I

COMPARISON OF BIT PERFORMANCE WITH AIR AND WATER DRILLING

	Air	Water
Drilled interval	60.7 m (199 ft)	78.3 m (257 ft)
Drilling time	39 h	42 h
Bit wear	0.64 cm (1/4 in.)	0.32 cm (1/8 in.)
Reamer wear	0.32 cm (1/8 in.)	0.16 cm (1/16 in.) and none
Drilling rate	1.6 m/h (5.1 ft/h)	1.9 m/h (6.1 ft/h)
Drill-string weight	20 Mg (44,000 lb)	20.8 Mg (46,000 lb)
Drilling speed, rpm	40	44

With steady drilling, a picture of the life of the Smith 9JS bits began to appear. At 40 to 50 rpm and a pressure of 17.2 Mg to 19.1 Mg (38,000 to 42,000 lb), a bit could be expected to last about 60 h, having drilled nearly 91 m (300 ft). After this amount of drilling, the bit was usually about 0.64 cm (1/4 in.) out of gauge, missing 15 to 25 buttons, and with the bottom reamers 0.16 cm to 0.32 cm (1/16 in. to 1/8 in.) out of gauge (Fig. 11).

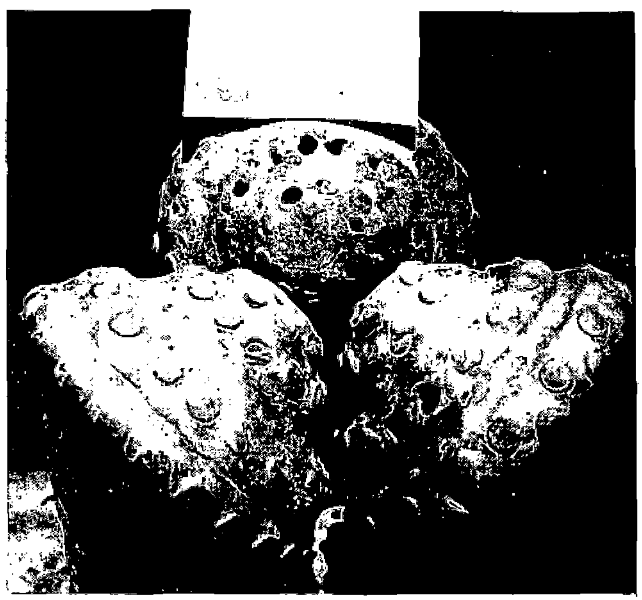


Fig. 11. Condition of Smith 9JS tricone rock bit after drilling for approximately 60 h. Note missing buttons.

TABLE II

SUMMARY OF MAJOR DRILLING RUNS IN GT-2

Drilled Depth	Drilled Interval	Drilling Time (h)	Rock Formation	Drilling Media	Bit Wear (Loss in diam)	Average Penetration Rate
870.8–959.2 m (2857–3147 ft)	88.4 m (290 ft)	27	Granite, granodiorite	Air	--	3.2 m/h (10.7 ft/h)
969.9–1055.5 m (3182–3463 ft)	85.6 m (281 ft)	32-1/2	Granite, granodiorite	Air	--	2.6 m/h (8.6 ft/h)
1162.5–1223.2 m (3814–4013 ft)	60.7 m (199 ft)	39	Granite	Air	0.64 cm (1/4 in.)	1.6 m/h (5.1 ft/h)
1223.2–1301.5 m (4013–4270 ft)	78.3 m (257 ft)	42	Granite	Water	0.32 cm (1/8 in.)	1.9 m/h (6.1 ft/h)
1304.2–1388.7 m (4279–4556 ft)	84.5 m (277 ft)	49-1/2	Granite	Water	0.64 cm (1/4 in.)	1.7 m/h (5.6 ft/h)
1388.7–1473.7 m (4556–4835 ft)	85.0 m (279 ft)	60-1/2	Granite, granodiorite, quartz monzonite	Water	0.64 cm (1/4 in.)	1.4 m/h (4.6 ft/h)
1499.9–1595.3 m (4921–5234 ft)	95.4 m (313 ft)	65	Granite, granodiorite, quartz monzonite	Water	0.64 cm (1/4 in.)	1.5 m/h (4.8 ft/h)
1597.2–1670 m (5240–5479 ft)	72.8 m (239 ft)	51	Granite, granodiorite	Water	0.64 cm (1/4 in.)	1.42 m/h (4.7 ft/h)
1727.9–1822.4 m (5669–5979 ft)	94.5 m (310 ft)	55-1/2	Granite, biotite schist, amphibolite	Water	0.32 cm (1/8 in.)	1.7 m/h (5.6 ft/h)

During the last 10 to 12 h of operation on a bit, a close watch was kept of the drilling rate. If the rate fell off significantly below the average 1.2 to 1.5 m/h (4 to 5 ft/h), or if the bit began to run rough or torque up, drilling would be halted and the bit pulled. Thus, a maximum possible usage was obtained while safeguarding against roller failure and disintegration in the hole.

A summarization of the major drilling runs is shown in Table II.

XII. CORING

As a comprehensive description of the coring program and coring equipment used in GT-2 is the subject of a separate report (to be published soon), only a cursory description is included here.

A. JOIDES Core Bits

The preliminary drilling program for GT-2 included a plan for obtaining intermittent cores in the sedimentary section and continuous cores in the crystalline section. It was planned to use the continuous wireline retrievable coring system currently used by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). Following the JOIDES design, Smith Tool Company manufactured 15 core bits, 24.4-cm-o.d. by 6.2-cm-i.d. (9-5/8-in.-o.d. by 2-7/16-in.-i.d.), with four carbide insert roller cutters to drill the hole and form the core (Fig. 12).

When used by the JOIDES Deep Sea Drilling Project, the inner core barrel is normally dropped from

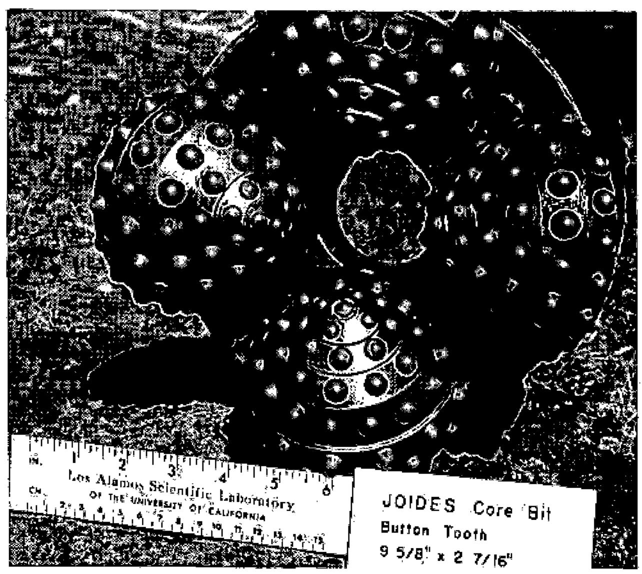


Fig. 12. JOIDES core bit.

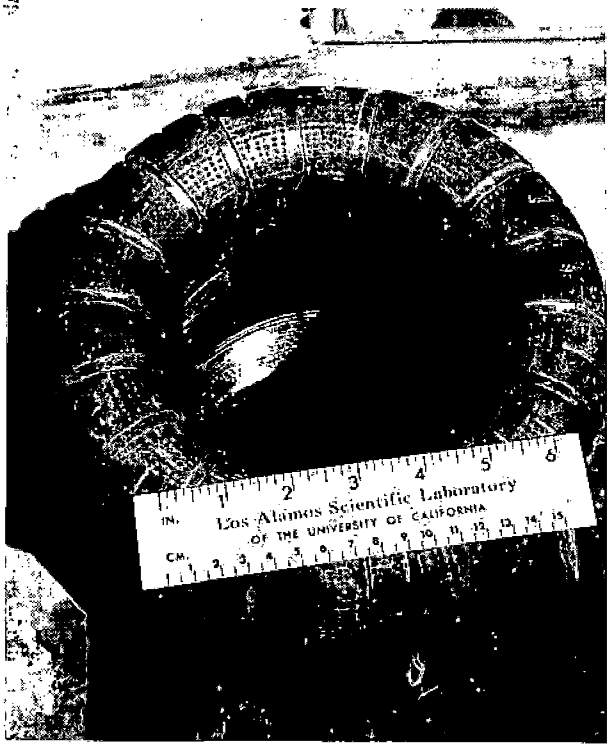


Fig. 13. Christensen diamond core bit.

the surface with the borehole full of water. As it was planned to drill the granitic rocks in GT-2 with air, modifications to the placing and retrieving components of the coring assemblies were necessary. A system to orient the cores with respect to their placement in the undisturbed native rock was also incorporated.

Many mechanical difficulties were encountered in fabricating and using the modified core orientation and wireline retrieval system. After the first three coring runs, the JOIDES bits were used as conventional bits, with no further attempt at wireline recovery. (Investigation and work continued on the continuous coring and retrieval problems, but on a diminshed scale.)

When used as conventional bits, the JOIDES design at first provided less-than-satisfactory recovery. A slight modification in bit design, beginning with Run No. 12, produced sufficient improvement to make the recovery comparable to conventional diamond bits. The coring operations are summarized in Table III, with the percent recovery of each core run, the type of bit and rock formation shown.

B. Diamond Core Bits

After the initial coring operations failed to produce the desired amount of core recovery, diamond core bits were used. Standard commercial bits

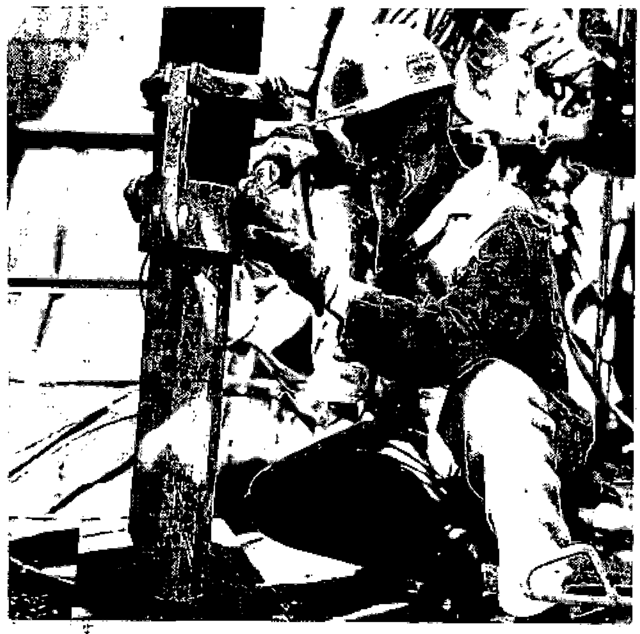


Fig. 14. Retrieval of first diamond core from GT-2. Note high-angle fracture.

(Fig. 13), Christensen Diamond Products Company 24.4-cm-o.d. by 11.4-cm-i.d. (9-5/8-in. by 4-1/2-in.), were employed to make four coring runs. The first run with a diamond bit (Fig. 14) was drilled at a penetration rate of 0.30 m/h (1 ft/h). This run produced 100% recovery (Fig. 15), but the bit life was only 3 m (10 ft). Subsequent modifications in diamond placement gave increased footage in later uses. Coring with diamond bits was discontinued after recovery with the JOIDES bits improved.

XIII. TEMPERATURE MEASUREMENT

A. Equipment and Frequency

Numerous temperature measurements were made in the hole using probes that were designed and fabricated by LASL. Several different types of temperature probes were constructed to suit the bottomhole conditions. The original instruments were designed

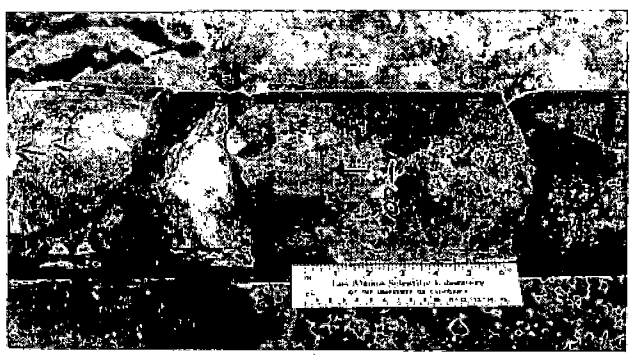


Fig. 15. Section of Core No. 9 showing a quartz pegmatite dike.

TABLE III

SUMMARY OF CORING RUNS FOR GT-2

Core Run	Cored Interval, Depth	Recovery (%)	Core Bit[a,b]	Rock Type[d]
1	633.4-639.5 m (2078-2098 ft)	25[c]	J	Clay w/limestone chips
2	685.2-688.2 m (2248-2258 ft)	50[c]	J	Shale w/limestone chips
3	776.3-786.4 m (2547-2580 ft)	35	J	Leucocratic quartz monzonite
4	789.4-792.5 m (2590-2600 ft)	33	J	Leucocratic quartz monzonite
5	862.9-866.9 m (2831-2844 ft)	30	J	Granite
6	866.9-870.8 m (2844-2857 ft)	20	J	Quartz monzonite
7	960.4-969.9 m (3151-3182 ft)	20	J	Biotite granodiorite
8	1055.8-1059.5 m (3464-3476 ft)	17	J	Leucocratic quartz monzonite
9	1125.9-1129.3 m (3694-3705 ft)	100	C	Leucocratic quartz monzonite
10	1303.9-1306.1 m (4278-4285 ft)	85	C	Leucocratic granodiorite and quartz monzonite
11	1491.1-1492.6 m (4892-4897 ft)	100	C	Biotite trondhjemite, leucocratic granodiorite, and quartz monzonite
12	1498.1-1499.9 m (4915-4921 ft)	100	J	Leucocratic quartz monzonite
13	1595.3-1597.1 m (5234-5240 ft)	38	J	Quartz monzonite, granodiorite
14	1672.4-1674 m (5487-5492 ft)	90	C	Quartz monzonite
15	1723.3-1725.2 m (5654-5660 ft)	92	J	Hornblende biotite schist
16	1822.7-1824.5 m (5980-5986 ft)	100	J	Hornblende biotite schist
17	1874.5-1876.3 m (6150-6156 ft)	66	J	Quartz monzonite
18	1876.3-1878.2 m (6156-6162 ft)	100	J	Quartz monzonite
19	1933.7-1935.5 m (6344-6350 ft)	16	J	Granodiorite
20	1935.5-1937.3 m (6350-6356 ft)	5	J	Granitic chips

[a] J - JOIDES bit.
[b] C - Christensen Diamond Products Company bit.
[c] Wireline core barrel retrieval.
[d] Rock type for Cores No. 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, and 19 determined from petrographic examination of thin sections. Identification of the remainder of the cores by hand specimen examination.

for a dry hole, but later probes were built for operation under pressurized wet conditions. A low-mass probe was used late in the program and proved to be very useful because of its fast response. In the lower regions of the hole, temperature measurements were scheduled at about 91-m (300-ft) intervals.

The average rate of temperature increase with depth in the crystalline rocks was 55°C/km. The bottomhole temperature was 137.5°C.

B. Circulation Procedure

The following procedure was developed to standardize the drilling-logging-coring sequence of operations.

1. After termination of drilling with a Smith 9JS full-face bit, circulation was maintained to clean the hole by stages.

(a) Pull bit 0.3 m (1 ft) off bottom, and circulate drilling fluid 1 min.

(b) Pull bit 1.5 m (5 ft) off bottom, and circulate 5 min.

(c) Pull bit 15.2 m (50 ft) off bottom, and circulate 1 h.

(d) Withdraw drill string from hole.

2. Run temperature logs (24 to 48 h).

3. Obtain core.

4. Resume drilling with full-face bit, for approximately 60 h.

Hourly bottomhole temperature measurements were recorded for periods up to 48 h. The rate of temperature increase for each logging run, as the bottomhole conditions approached equilibrium, usually allowed a reasonable extrapolation of final temperatures to be made after about 40 h of measurements. However, on June 25, at a depth of 1670 m (5480 ft), a temperature of 125.4°C was obtained which did not seem to follow a predictable pattern of increase. A fracture zone had been encountered near the bottom of the hole, and this zone may have been abnormally cooled by the entrance of drilling fluid.

C. High-Viscosity Mud

Prior to obtaining the last three temperature measurements, a slug of high-viscosity mud was placed in the bottom of the hole to prevent convective circulation. The mud consisted of 16 bbl of Aquagel mix (185 s viscosity) with eight sacks of barite powder.

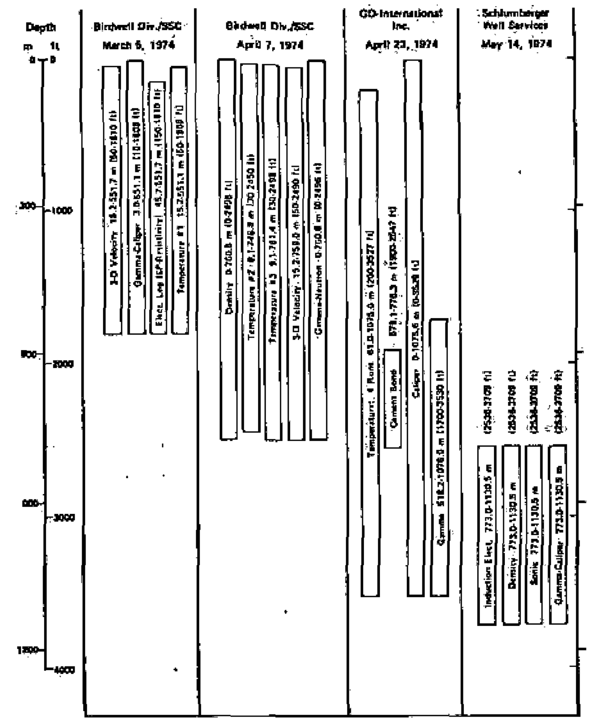


Fig. 16. Diagnostic logging services performed in GT-2 from March through May 1974.

XIV. LOGGING

Diagnostic logging operations were performed in the hole by three commercial logging companies, by the U. S. Geological Survey (USGS), and by personnel of the Los Alamos Scientific Laboratory.

A total of eight diagnostic logging operations were performed by commercial logging companies. Summaries of these logging operations are shown in Figs. 16-18, which designate the depths that each type of log was run, the dates and the company that performed the work.

The U. S. Geological Survey conducted televiewer surveys of the hole between depths of 996-1021 m (3270-3350 ft) and 1050-1094 m (3445-3590 ft), and temperature, caliper, and single-point resistivity logs at varying depths. The USGS televiewer logs were not oriented because the magnetometer failed to operate at the temperatures encountered in the hole at those depths.

Logging operations by LASL consisted only of temperature surveys.

At various depth intervals, a significant increase in hole diameter was observed between successive caliper logs. These zones of diameter increase were noted at depths of 917-923 m (3008-3030 ft),

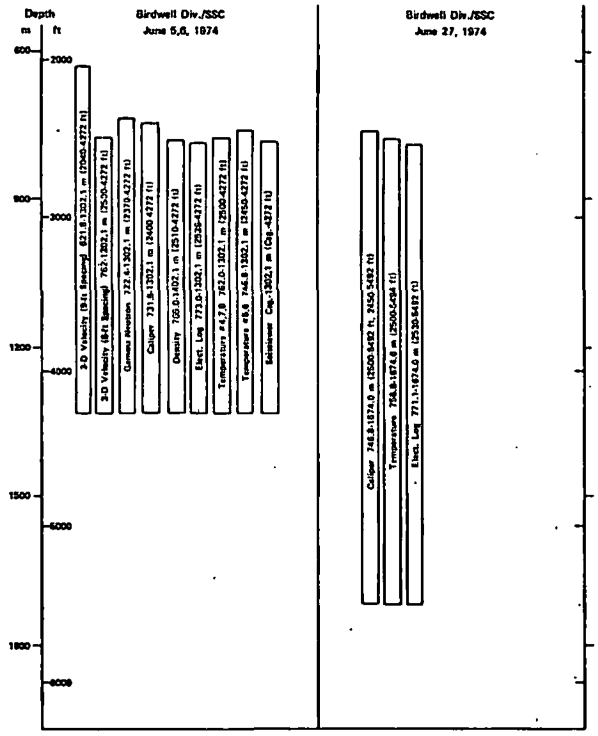


Fig. 17. Diagnostic logging services performed in GT-2 during June 1974.

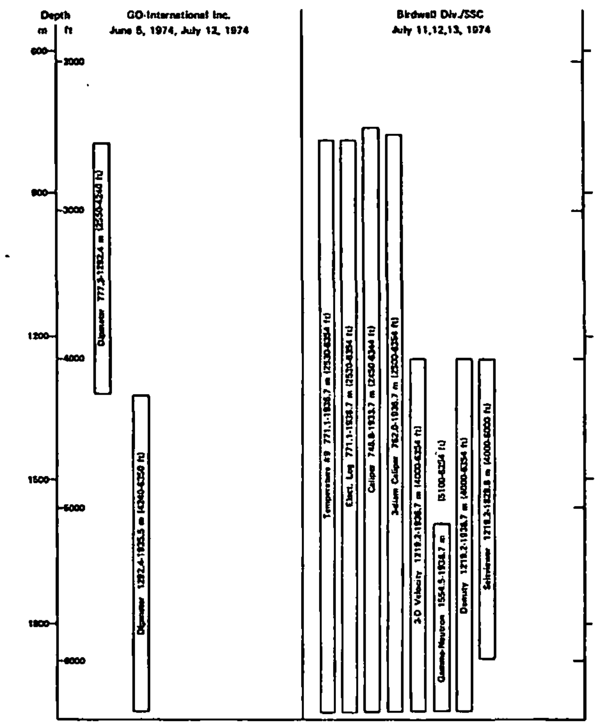


Fig. 18. Diagnostic logging services performed in GT-2 during June and July 1974.

1172-1180 m (3845-3870 ft), and 1270-1289 m (4166-4230 ft), where the maximum diameter changed from 28 to 39 cm (11 to 15.5 in.).

In general, the sonic, 3-D and gamma-gamma logs displayed an excellent correlation with the caliper logs. Lower sonic velocities and lower bulk densities were measured in the larger diameter sections of the hole. The neutron and resistivity logs also showed a good correlation with the caliper logs, in that higher apparent porosities and lower resistivities were recorded in the larger diameter sections.

Additional discussion of the logging operations is included in Section XV.

XV. COMPARISON WITH PLAN

A. Sediments, Phase I-A

1. Measurements. Due to extremely difficult drilling conditions, a few of the proposed drilling-related measurements as outlined in Phase I-A of the drilling plan (Appendix B) were not made. All efforts were directed toward keeping the hole open to enable drilling to continue, rather than possibly sacrificing the hole for the sake of the measurements.

a. Accurate drilling rates were recorded and effective bit life was determined for most of the hole. Obviously, the drilling records are of no value when redrilling through cement or through caving zones was done.

b. Only three attempts at coring were made in the sedimentary beds above the granite. When drilling was in progress in the upper, more competent beds, the necessary coring equipment had not yet arrived on the job site. Later, when coring apparatus was available, the lower sedimentary beds did not lend themselves to it. Also, because of the caving conditions encountered in the Madera and Sandia Formations, any shutdown of the drilling operation to pull core samples invited disaster from increased caving.

c. Stabilized bottomhole assemblies were used in all drilling operations and the small amount of hole deviation (maximum 1-3/4 degrees from the vertical) can be attributed to this practice.

d. Much was learned about mud drilling in the Permian and Pennsylvanian sediments, and this knowledge can be applied in outlining a more effective mud program for future drilling.

e. Because of the high usage of lost-circulation materials and the need for constant replenishment of the drilling mud due to leakage into the formation, it was not possible to maintain useful records of fluid-circulation and heat-removal rates from the hole.

f. Drill cuttings were obtained at 3-m (10-ft) intervals and have been used extensively for interpreting the lithology of the Paleozoic sediments.

2. Coring Measurements. Cores were not obtained in the upper part of the granite surface as planned because of the severe caving of the sediments immediately above the granite. As much footage was made as quickly as possible to get out of the hole with the drill pipe and to set the deep casing in place.

3. Diagnostic Logs. Prior to setting the 34-cm-diam (13-3/8-in.) surface casing, three groups of diagnostic logs were run in the open hole by Birdwell Logging Company. These consisted of temperature, gamma ray and caliper in the first run; electric logs with a self-potential and short-normal, long-normal and 5.5-m lateral spacing in the second run; and the 3-D velocity log with 2-m and 3-m spacings in the last run. The logs were of inestimable value in determining the depth to a competent bed of limestone in which the casing could be set. The logs were also helpful in determining the depth of the top and bottom of the Abo Formation. (The red color of the Abo stained the drilling mud and colored the cuttings from the top of the Madera Limestone, making this boundary difficult to distinguish visually.)

An attempt to obtain another set of diagnostic logs was made before setting the deep string of casing, but could not be accomplished due to caving and bridging in the hole.

4. Post-Cementing Studies. After the 27.3-cm-diam (10-3/4-in.) casing had been set and cemented 40 m (130 ft) into the granite, logs were again run by Birdwell to determine the cement bond and temperature, as well as full-depth gamma and neutron logs. A 3.6-m (12-ft) section of hole was drilled below the casing and satisfactorily pressure tested.

The majority of the mud-drilling-related measurements and activities as set forth in the proposed plan for Phase I of GT-2 were accomplished. The two notable exceptions were the fluid-circulation rate and heat-removal measurements, and the coring activities.

B. Granitic Basement, Phase I-B

1. Measurements. The Phase I-B plan for drilling-related measurements and studies in the crystalline rocks was based on two major assumptions: (1) that presently developed drilling equipment would be suitable for performing the continuous coring drilling operations, and (2) that all drilling would be done with compressed air in a relatively impermeable formation. As neither of these presupposed conditions was encountered, this drilling phase was quite different than that which had been envisioned.

A discussion of the coring operations and air drilling has been covered in other sections of this report.

Although the operating conditions were quite different than those that had been anticipated, most of the planned measurements were obtained.

a. Circulating air flow rate was not obtained. Air circulation was not maintained with any regularity after excessive water was encountered in the hole. Air pressure in the bottom of the hole would build up to a point sufficiently high to blow the water out, and the hole would unload temporarily.

b. Air inlet and outlet temperatures were not recorded because of the difficulties with unloading the hole. However, after conversion to water drilling, the circulating water inlet and outlet temperature levels were continuously recorded at the LASL logging van.

c. Circulating air inlet pressure was continuously recorded during the short-lived air-drilling phase.

d. Rotary table revolutions (rpm) were not continuously recorded, but frequent notations of the bit rpm were recorded in the daily log.

e. Hook load was continuously recorded on the TOTCO Drilling Recorder.

f. Hole depth was continuously recorded on the TOTCO Drilling Recorder from the beginning of the operation.

g. Drilling rate was recorded by the TOTCO Continuous Drilling Rate Logger.

2. Drilling-Related Studies

a. Coring rates were obtained when coring operations were in progress. Penetration rates were likewise recorded for the full-face bits in both air and water drilling. The type of crystalline rock, except for badly fractured zones or thick soft veins, seemed to have little effect on the drilling rate.

b. With the formation accepting water most of the time, it was impractical to try to measure the amount of heat removed from the formation.

c. An on-line effluent analysis for trace contaminants was not maintained. Downhole gas and water samples were taken periodically when temperature measurements were made.

3. Core Studies and Measurements. Each section of recovered core was examined, labeled, petrologically identified and petrographically studied in the field soon after extraction. Existing fractures, their orientation, and the degree and type of cementation were recorded on sketch sheets for each core run. Sonic velocity measurements were also made in the field on selected cores to determine if any anistropy existed in the freshly-recovered core and if any changes in properties occurred during the period required to transport the cores from the drilling site to the laboratory.

The core was taken to LASL soon after extraction for subsequent detailed petrographic and petrofabric studies, and for measurement of selected physical, thermal, and chemical properties.

In addition to the core samples, cuttings were collected from the flow line or shale shaker at 1.5-m-depth (5-ft) intervals. These cuttings proved very useful in determining lithologic changes in the formation and as a guide in determining the depths at which cores should be taken.

4. In Situ Temperature Measurements. Although temperature measurements were not made at the intervals originally specified (because of the longer time required to reach equilibrium than had been anticipated), enough measurements were obtained to determine the thermal gradient (see Section XIII, on temperature measurements).

5. Diagnostic Logs. More logging runs were made than had originally been scheduled. In view of the lack of core information to establish the character and integrity of the rock formations, the information obtained by the diagnostic logs was invaluable. The dipmeter log was especially useful in mapping the orientation of fractures exposed in the borehole.

REFERENCES

1. D. W. Brown, "The Potential for Hot-Dry-Rock Geothermal Energy in the Western United States," Hearings before the Subcommittee on Energy of the Committee on Science and Astronautics, U.S. House of Representatives, Ninety-Third Congress, First Session on H.R. 8628, H.R. 9658, Sept. 11, 13, and 18, 1973, pp. 129-138.

2. D. W. Brown, M. C. Smith, and R. M. Potter, "A New Method for Extracting Energy from 'Dry' Geothermal Reservoirs," Proc. Twentieth Annual Southwestern Petroleum Short Course, Texas Tech Univ., Lubbock, Texas, April 26-27, 1973, pp. 249-255.

3. B. C. Renich, "Geology and Ground-Water Resources of Western Sandoval County, New Mexico," USGS Water-Supply Paper 620 (1931).

4. G. H. Woods, Jr., and S. A. Northrop, "Geology of the Nacimiento Mountains, San Pedro Mountains, and Adjacent Plateaus in Parts of Sandoval and Rio Arriba Counties, New Mexico," USGS Oil and Gas Inv. Prelim. Map 57 (1946).

5. R. L. Smith, R. A. Bailey, and C. S. Ross, "Structural Evolution of the Valles Caldera, New Mexico, and Its Bearing on Emplacement of Ring Dikes," USGS Prof. Paper 424-D (1961).

6. C. S. Ross, R. L. Smith, and R. A. Bailey, "Outline of Geology of the Jemez Mountains, New Mexico," N. M. Geol. Soc. Twelfth Field Conf., Albuquerque Country (1961).

7. R. A. Bailey, R. L. Smith, and C. S. Ross, "Stratigraphic Nomenclature of the Volcanic Rocks in the Jemez Mountains, New Mexico," USGS Bull. 1274-P (1969).

8. R. L. Smith, R. A. Bailey, and C. S. Ross, "Geologic Map of the Jemez Mountains, New Mexico," USGS Misc. Geol. Inv. Map I-571 (1970).

9. J. P. Fitzsimmons, "Precambrian Rocks of the Albuquerque Country," New Mexico Geol. Soc. Twelfth Field Conf., Albuquerque Country (1961).

10. F. G. West, "Regional Geology and Geophysics of the Jemez Mountains," Los Alamos Scientific Laboratory report LA-5362-MS (1973).

11. W. D. Purtymun, "Geology of the Jemez Plateau West of the Valles Caldera," Los Alamos Scientific Laboratory report LA-5124-MS (1973).

12. W. D. Purtymun, F. G. West, and R. A. Pettitt, "Geology of Geothermal Test Hole GT-2, Fenton Hill Site," Los Alamos Scientific Laboratory report to be published.

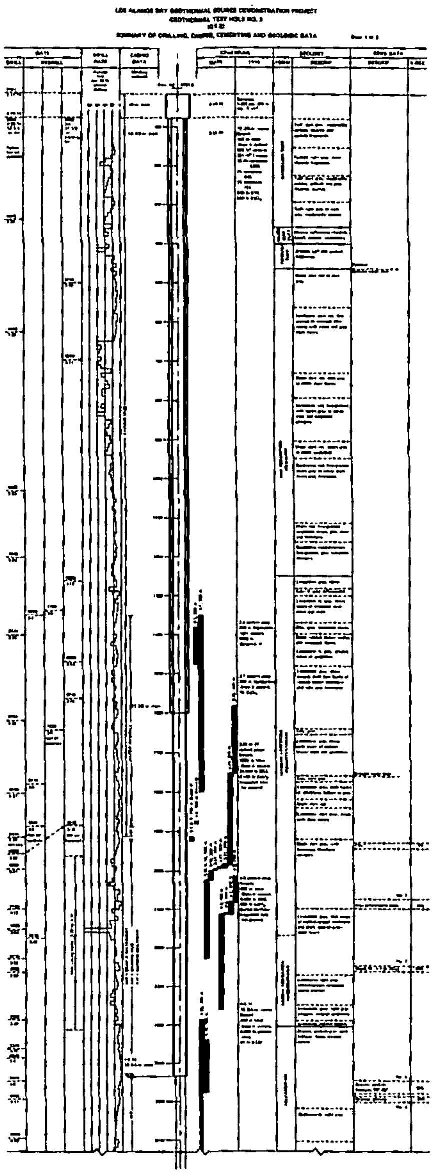
13. F. G. West, "Geohydrology of the Jemez Plateau," paper presented at the Annual Fall Meeting, 1973, American Geophysical Union, San Francisco, CA, December 10, 1973.

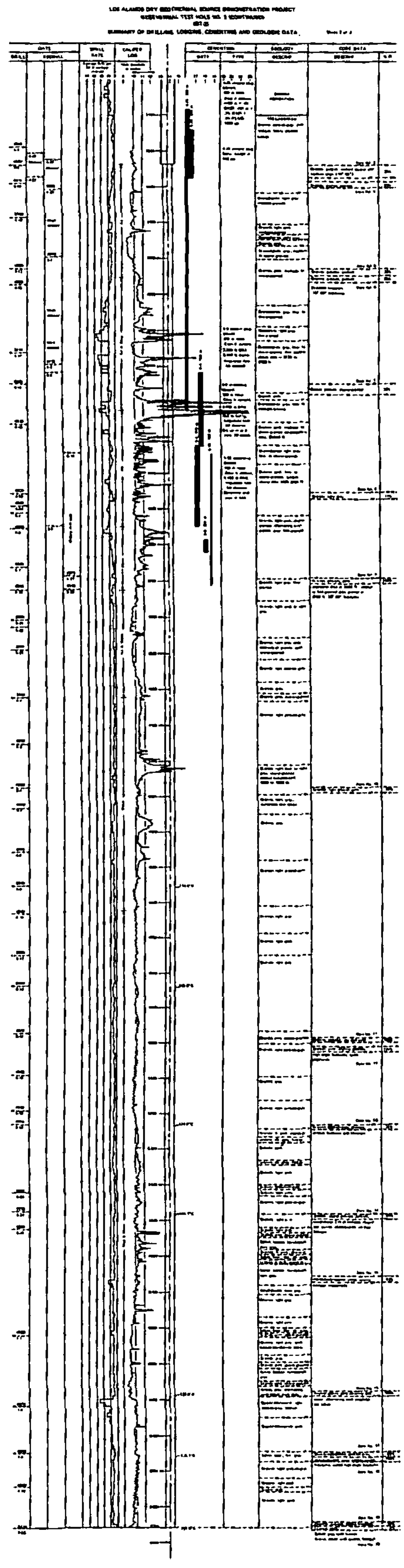
14. R. L. Aamodt, "An Experimental Measurement of In Situ Stress in Granite by Hydraulic Fracturing," Los Alamos Scientific Laboratory report LA-5605-MS (April 1974).

APPENDIX A

SUMMARY OF DRILLING, CASING, CEMENTING AND GEOLOGIC DATA

For an original-size copy of this appendix, send your request to the author.





APPENDIX B

EXPERIMENTS AND MEASUREMENTS PLANNED DURING THE DRILLING PHASE OF GT-2

March 20, 1974

A. During the Mud-Drilling Phase of GT-2 (through the volcanics and Paleozoic sediments, and about 76 m (250 ft) into the underlying Precambrian basement rocks--to a total depth of about 790 m (2600 ft)).

1. Drilling-Related Studies. During the mud-drilling phase of GT-2, a variety of studies will be made that will help in the planning and execution of the subsequent drilling program for EE-1 and EE-2, the deeper and shallower legs of the planned two-hole circulation experiment.

a. Drilling Rates. Accurate drilling rates using a well-stabilized and stiff bottomhole assembly will be obtained for 311-mm-diameter (12-1/4-in.) drilled holes in granite (or other basement crystalline rocks) using mud as the circulating fluid. Drilling rates in the upper volcanics and sediments will also be determined.

b. Coring Rates. Accurate penetration rates during coring with a Deep Sea Drilling type, roller-cutter core bit will be obtained for a wide variety of rock types.*

c. Results from the Packed-Hole Drilling Assembly. The effective bit (actually bearing and insert) life and minimized hole deviation resulting from the use of a stiff, stabilized, bottomhole assembly will be assessed for future drilling programs.

d. Development of an Effective Mud Program. The Permian red beds, underlying much of the Southwest and Texas,** as well as the sedimentary basins of the Rocky Mountain West, are renowned for causing severe drilling problems.

However, with an experienced mud engineer from a good mud company, a suitable mud program will be developed to permit the drilling of the Abo Formation (with its swelling clays, lost circulation and caving formation problems), and then to maintain a stable hole through this 270-m-thick section of red beds while drilling an additional 300 m through the older Paleozoic sediments and into the Precambrian basement.

e. Fluid Circulation Rate and Heat Removal. The circulating fluid flow rate and inlet and outlet temperatures will be constantly recorded during the mud-drilling phase of GT-2 for subsequent temperature profile corrections.

f. Cuttings Analysis. Drill cuttings (a representative sample to be obtained for every 3-m interval), augmented by cores and diagnostic logs, will be used in interpreting the lithology of the surface volcanics and Paleozoic sediments and the petrology of the Precambrian basement.

2. Coring and Related Core Measurements

a. While Drilling the Paleozoic Sediments. A 9.1-m (30-ft) core will be cut approximately every 60 m. These cores, cut at a 62 mm (2-7/16 in.) diameter, will be field examined for stratigraphic and related geologic information; and then stored for a laboratory determination of thermal conductivity, density, permeability, and other properties as a function of depth.

b. At the Top of the Precambrian Basement. Depending on core-bit performance, the top 6 to 9 m of the crystalline basement rock will be cored to provide an accurate determination of the degree and depth of the weathered zone, and to give an indication of the joint pattern at and just below this ancient surface. A petrographic study of these cores may yield much information on this geologic surface.

c. At 30-m Intervals Below the Precambrian Surface. If the first coring and subsequent hole-opening operations in the crystalline basement rock are successful (as appears probable), additional 6-m cores will be cut thereafter approximately every 30 m. The primary purpose of these cores is to determine whether, at successive 30-m intervals below the Precambrian surface, steel casing set and cemented at each such depth would adequately isolate the remainder of the hole from the overlying sedimentary

*Since this will be the first use of the JOIDES-developed core bit for continental drilling, its performance while drilling through a representative geologic section--including a section of basement rock--will be of vital interest to any future deep continental exploratory drilling program.
**Referred to as the Abo Formation in New Mexico.

formations, particularly during post-drilling high-pressure hydraulic fracturing experiments. Therefore, the actual casing setting depth will be determined from a field examination of these cores.

d. Oriented Cores. If sufficient time is available to obtain the required equipment, the cores will be magnetically oriented. From the sedimentary cores, paleostructural information (the strike and dip of bedding planes and paleomagnetic information) can be obtained for that portion of the Paleozoic era represented in the Jemez Plateau area.

3. Diagnostic Logs. Following the completion of the mud-drilling phase of GT-2, but prior to setting and cementing casing (unless the particular log can be run through casing), a complete suite of diagnostic logs will be run in the open hole by a commercial logging company (Schlumberger, Birdwell, or equal). Using a variety of standard oil-field logging tools, and several recently developed special logging and/or diagnostic techniques, the variation with depth of formation lithology and a variety of significant rock physical properties will be measured. The rock properties to be determined by the combination of these logging techniques include:

a. Elastic Properties. The compressive and shear wave velocities will be measured in situ by the use of a full wave continuous velocity recording sonde (3-D velocity log). Poisson's ratio can be found by the relationship between the compressive and shear wave velocities. Poisson's ratio is a parameter in the equations of elasticity which express the relation between the principal stresses. Using the compressive and shear velocities and the bulk density, the shear modulus and Young's modulus can be computed for use in the analysis of the mechanical reaction of the rock to a particular stress field.

b. Bulk Physical Properties. The bulk density of the rock will be measured by use of a gamma-gamma sonde which records the back-scattered gamma radiation resulting from the rock being exposed to a source of gamma radiation. Inferences as to the porosity of the rock can be made from the neutron log, the velocity log and the electric logs.

c. Electrical Properties. The resistivity will be measured using several sonde electrode spacings to give various depths of investigation. Spacings to be used are short normal (0.4 m), long normal (1.6 m), and the 5.5-m lateral. The guard (or SP) log, which utilizes an induced electromagnetic field to measure resistivity, will also be used. The natural electric self-potential generated by streaming potentials or electrokinetic phenomena will be logged to help define lithologic changes and possible water movement.

d. The Strike and Dip of Bedding Planes and the Presence of Fractures. A device known as the dipmeter (using three wall electrodes) will be used to map the character of the borehole wall, especially the spatial orientation of bedding planes and fractures. The "3-D" velocity tool will also give information as to the mechanical nature of any observed fractures.

e. The Degree of Formation Induration. The variation of the borehole diameter as seen on the caliper log is a relative indication of the rock induration.

For the above rock physical property determinations, and for associated lithologic studies, the following logging tools will be used.

a. Caliper log*
b. Induction-electrical survey*
c. Density (scattered gamma) log
d. 3-D sonic velocity log*
e. Gamma log (natural gamma activity)
f. Dipmeter survey*
g. Neutron-activation log (primarily a function of the hydrogen (water) content of the adjacent rock)
h. Temperature log

4. Post-Cementing Studies. After the casing has been cemented in place and the cement allowed to set up (about 36 h), the cement will be cleaned out of the pipe with a 244-mm (9-5/8-in.) drill bit, the float shoe drilled out, and about 3 m of hole drilled below the casing. The circulating fluid for this brief drilling operation will be water. After pulling the bit, a cement-bond log,** temperature log, and a nuclear cement log will be run to determine the quality and integrity of the cement job. These logs will show any regions where the cement is not bonded to the casing, or zones where the cement slurry has channeled.

*Must be run in the open hole prior to setting casing.
**A special use of the "3-D" log.

Finally, a pressure check of the short openhole section and the casing will be made. The object of this test is to assure that the cemented casing and adjacent basement rock form a sufficiently impermeable barrier between the remainder of the open hole and the overlying Paleozoic sediments.

B. During the Continuous Coring Phase of GT-2 (Drilled in Precambrian basement rock, from about 0.79 km to a final depth of about 1.37 to 1.83 km).

Continuous coring in crystalline rocks will present a unique opportunity to correlate the various drilling functions with the physical properties subsequently measured on the cores, for use in the advancement of drilling technology. During the continuous-coring phase of GT-2, the following drilling-related functions will be continuously recorded.

a. Circulating air flow rate.

b. Circulating air inlet and outlet temperature levels.

c. Circulating air inlet pressure.

d. Rotary table (bit) revolutions per minute.

e. Hook load: that portion of the total drill string weight being supported at the surface. (From this measurement, the corresponding weight on the bit can be calculated.)

f. Hole depth.

g. Drilling rate (min/ft).

1. Drilling-Related Studies. During the continuous-coring phase of GT-2, an additional group of drilling studies will be made that will be pertinent not only to the subsequent drilling of EE-1 and EE-2, but also to any future continental deep geosciences drilling program. This phase of the GT-2 drilling program represents the first known use of a tapered-cone roller cutter core bit* for coring in continental crystalline basement rock, and has the potential for placing LASL in a preeminent position relative to any future U. S. deep geosciences drilling program.

a. Coring Rates. Accurate coring rates, using a well-engineered bottomhole assembly (reasonably stiff and well-stablilized), will be obtained for the air drilling of a variety of crystalline basement rocks. In addition, an analysis of the continuously recorded values for rpm, bit weight and penetration rate, in conjunction with core-derived petrologic information, will allow a determination of the optimum set of drilling conditions for each type of rock penetrated.

*As compared to the previous use of much slower drilling (and much more expensive) diamond core bits.

b. Coolant Flow Heat Balance. The measured coolant air-flow parameters will allow a post-drilling analysis of the formation heat removed during the air-drilling phase of the operation. This will permit a better evaluation--than was possible for GT-1--of the thermal recovery of the hole with time.

c. Effluent Air-Flow Analysis for Trace Contaminants. An initial request to H-Division (H-5) has been made to provide an on-line effluent analysis during the air-drilling phase of GT-2, for noxious or hazardous trace contaminants such as H_2S, CO, and CH_4.

2. Oriented Coring Program. Cores from the entire drilled section of igneous and metamorphic rock below the casing setting depth (at about 0.79 km) will be recovered in a continuous coring operation. Wireline recovery techniques, developed for the Deep Sea Drilling Program, will be used to recover the core in 9-m sections. The drilled hole diameter for coring operations will be 244 mm (9-5/8 in.), with a core diameter of 62 mm. Each section of core will be described following core recovery. The core orientation will be determined magnetically to allow subsequent determinations of the actual strike of any exposed fractures or other rock structural features.

3. Core Studies and Measurements. Each recovered section of core will be examined initially in the field.* The rock will be labeled, petrologically identified, and visually studied, noting any existing fractures, their orientation, and the degree and type of cementation on individual core-run sketch sheets. The core will then be trucked to LASL for subsequent detailed petrographic and petrofabric studies, and for the measurement of selected physical, thermal, and chemical properties. The distribution of individual core pieces for the various studies will be recorded in a core library log book.

*The orientation and depth of the cored interval will be entered in a drill site log book. The core orientration will also be permanently marked on the core as it is broken into nominal 1.5-m (5-ft) lengths.

a. Programmatic Core Studies and Measurements. Before proceeding with the drilling phase of the two-hole circulation experiment adjacent to GT-2, certain specific core studies and measurements will be performed. Primary among these is an assessment, based on an intial examination of the fracture patterns shown in the cored interval of Precambrian basement rock (580 m or more), of the natural fracture system anticipated at the projected depth for EE-1 (about 2.3 to 2.8 km as discussed later). One would anticipate that the number of fractures would decrease with depth below the Precambrian surface, but this assertion must be verified.*

In addition, the room-temperature thermal conductivities of selected Precambrian core samples will be measured in the laboratory (in a saturated condition if possible). Combined with the measured temperature gradient (and the second order effect of the variation in radiogenic heat generation if available), these data will allow an extrapolation of temperature to the projected depth for EE-1. Based on the best available heat-flow and rock-conductivity data from GT-1 and the previous four deep heat-flow holes, the projected temperature at the bottom of EE-1 is expected to be 230°C at a depth of 2.3 km, and 275°C at a depth of 2.8 km. However, these projections will be improved, based on the temperature profile data and thermal conductivity values obtained from GT-2.

b. Later Core Studies Relating to Subsequent Geosciences Experiments. Though seldom mentioned, one of the distinct advantages of a complete core record is in the planning and analysis of subsequent small-scale hydraulic fracturing experiments. Based on the experience gained from the fracturing experiments in GT-1, a knowledge of the rock type and an accurate picture of the existing fracture pattern (number, orientation, and degree of cementation) for the zone to be fractured, is a decided help in analyzing and interpreting the experimental results.

*From previous in situ studies of GT-1, the presence of pre-existing hydrothermally cemented fractures results primarily in the lowering of the required hydraulic pressure for fracture initiation by several tens of bars below that for unfractured rock. That is, these cemented fractures represent zones of relative weakness (in terms of tensile strength), but have no apparent effect on the bulk permeability of the rock.

A detailed petrographic analysis of representative core samples, for mineral content, degree of hydrothermal alteration, and trace element content, will be needed for subsequent laboratory and in situ geochemical studies. These petrographic analyses, in combination with age-dating and structural information, will permit a broader geological study of the Precambrian basement underlying the Jemez Plateau and the influence on it of the adjacent Valles volcanic complex.

Since radioactive decay processes are believed to be the major source of heat generation within the earth, it would be desirable, programmatic considerations permitting, to perform a study of the heat generation and radioisotope distribution along the GT-2 cores, as an approach to the problem of the evaluation of the fraction of total heat flow which can be ascribed to radiogenic heat production in the rocks. The complete interpretation of heat-flow data requires a knowledge of the distribution of the major radioactive elements ^{238}U, ^{235}U, ^{232}Th, and ^{40}K within the crust and upper mantle. Most of our present knowledge of this distribution is restricted to near-surface rocks, so that the distribution of radioelements at depth can only be inferred from what we see near the surface. These new data not only give added insight on the hypotheses of various authors, but would provide a comparison standard for the possible development of tools for in situ measurements of radioisotope distributions.

4. In Situ Temperature Measurements. During the continuous-coring phase of GT-2, the rock temperature at the bottom of the hole will be measured every 18 m (following every other core recovery.) These measurements will be made using a special wireline tool lowered through the center of the drill string and core bit, and coming to rest on top of the short stub of rock projecting from the bottom of the hole after core recovery. The bottom of this tool will be fitted with an insulated, spring-loaded, thermistor probe (accurate to about ±0.05°C). Above the thermistor probe and a section of thermal insulation, the tool will contain two evacuated, surface-actuated, gas-sampling bottles.

The least thermally disturbed region of rock at any time during the drilling operation is at the very bottom of the hole. For example, the material around the 100-mm-long stub of cored rock left at the bottom of the hole following each core recovery will have been removed by drilling in less than 2 min. Further, this stub of rock will have almost 2 h for thermal recovery between the time that air circulation is stopped and the time that the temperature sonde finally reaches the bottom of the hole.

After the temperature sonde reaches the bottom of the hole, the continuing thermal recovery of the rock at the bottom of the hole will be monitored for approximately 30 min. Analytical studies suggest that a close approach to an undisturbed rock stub temperature can be achieved by controlling the drilling process (rate of penetration, circulating air flow rate, and drill bit energy input).

During this time, two samples of the connate fluids outgassing from the surrounding rock will be collected for subsequent chemical analyses, particularly for the ^{16}O to ^{18}O ratio (a potential geochemical thermometer).

5. Diagnostic Logs (Dry Hole). Following the completion of the continuous-coring phase of GT-2, a second suite of diagnostic logs will be run by a commercial logging company, including several full-depth temperature logs ($\pm$0.3°C). Essentially the same measurements that were previously made in the upper hole will be repeated for the lower section of the hole, except for those logs that must be run in water. The diagnostic logs that will be run at this time will include:

a. Temperature. This will be the first log (run as soon as the hole is available), and it will be repeated at the end of the logging sequence.

b. Caliper* (run in combination with the gamma and neutron logs).

c. Density* (scattered gamma).

d. Neutron (^{60}Co neutron source).

e. Gamma (natural activity).

The neutron log will be run in both the dry and fluid-filled holes in an attempt to assess fluid penetration into any existing open fracture systems.

*Run from just above the bottom of the casing to the bottom of the hole.

APPENDIX C

SPECIFICATIONS FOR GEOTHERMAL TEST HOLE NO. 2

October 31, 1973

Specification No. LAB-SP-3379

PART C-I

SPECIAL CONDITIONS

SC-01. STATEMENT OF WORK

A. Location. The drilling site for GT-2 is located in the northeast quadrant of Section 13, T19N, R2E, Sandoval County, New Mexico. The site, at an elevation of 8690 ft, is within the Jemez Springs Ranger District of the Santa Fe National Forest, in an area referred to geographically as the Jemez Plateau. The drilling site is adjacent to State Highway 126, 40 road miles west of Los Alamos and 15 road miles north of Jemez Springs. A 200-yd-long access road is available to the drilling location.

B. Description of Work. The work consists of furnishing all personnel, equipment, facilities, materials, supplies, fuel and services, unless otherwise specified, to perform the following.

1. Drill a 12-1/4-in. hole, with intermittent coring, to a depth of approximately 2600 ft using mud as the circulating fluid; run logs and surveys as directed.

2. Run and set 10-3/4-in. casing at 2600 $\pm$ ft; cement as directed.

3. Continuously core a 9-5/8-in. hole to a depth of 6000 ft, or until a total of 57 days have elapsed since the beginning of drilling operations (not including standby-secured days). In the event that the minimum specified depth of 4500 ft has not been reached within this 57-day time limit, the University* retains the option of extending the

*The Los Alamos Scientific Laboratory of the University of California, here and after referred to as the University.

drilling program until this minimum depth of 4500 ft has been reached.

C. University-Furnished Items. The University will furnish, for the work under this contract, the items listed in Part C-I.

D. Seller (Contractor) Minimum Equipment Requirements. The minimum equipment and services to be furnished and operated by the Seller (Contractor) at no additional cost to the University are listed in Part C-VI.

Note: In all subsequent portions of these specifications, the "Seller" will be referred to as the "Contractor."

E. Contractor-Furnished University-Reimbursable Items. Equipment and services which the Contractor may be required to furnish and the cost thereof reimbursed under the provision of SC-05, Paragraph 5, Special Items and Services, are listed in Part C-VII.

SC-02. COMMENCEMENT OF WORK

The Contractor shall complete mobilization within 15 calendar days after the date of receipt of the notice to proceed. It is expected that this notice will be given in early January 1974.

SC-03. CONTRACTOR'S WORK WEEK AND PERSONNEL REQUIREMENTS

The Contractor shall furnish qualified personnel sufficient to maintain a 24-h day, 7-day work week operation with a five-man crew as follows:

1 Supervisor available at all times.
1 Driller for each crew.
1 Derrickman for each crew.
2 Rotary Helpers for each crew.
1 Motorman for each crew.

SC-04. ACCOMMODATIONS FOR CONTRACTOR'S PERSONNEL

No University-furnished camping or messing facilities will be available. Commercial accommodations and eating facilities are available in both Jemez Springs and Los Alamos.

SC-05. UNIT PRICE ITEMS DEFINED

1. Mobilization. All moving-in and rigging-up operations shall be performed by the Contractor and paid for under Item No. 1 of the Unit Price Schedule (Part C-IX). Mobilization shall be complete when all equipment is rigged up, operational and the Contractor is ready to enter the conductor hole in preparation to start the 12-1/4-in. hole.

2. Hourly Rate Operations. All operations under this category shall be at the direction of the University, and will be performed with a full complement of operating personnel. These operations shall include, but will not be limited to, the following:

(1) Coring;
(2) Reaming;
(3) Drilling;
(4) Logging;
(5) Testing;
(6) Running casing;
(7) Cementing;
(8) Waiting on cement;
(9) Waiting for orders;
(10) Hydraulic fracturing.

a. With Drill Pipe. Hourly rate operations requiring any part of the drill string (drill pipe) to be below the rotary table will be paid for under Item No. 2.a. of the Unit Price Schedule, Part C-IX.

b. Without Drill Pipe. Hourly rate operations without drill pipe will be paid for under Item No. 2.b. of the Unit Price Schedule.

3. Standby-Secured. When directed by the University, the Contractor shall cease all operations. All equipment may be secured and personnel need not be in attendance. Standby-secured rates will continue until normal operations are resumed, but under no circumstances shall exceed 24 hours after receipt of notice from the University to resume operation. Standby-secured time will be paid for under Item No. 3 of the Unit Price Schedule.

4. Demobilization. Upon completion of the work under this contract, the Contractor shall remove all rubbish, debris and his equipment from the drill site. All materials, work and services required for demobilization by the Contractor will be paid for under Item No. 4 of the Unit Price Schedule. The Contractor will not be responsible for restoring the work site or draining the reserve pit.

5. Special Items and Services

a. In the event the Contractor should purchase or rent special tools, materials, and services at the direction of the University (including fuel), the University will pay the Contractor the actual invoice cost including sales tax where applicable, of such tools, materials, and services delivered to the work site less all discounts, refunds, rebates, and salvage allowances to which the Contractor is entitled.

b. The Contractor will deliver applicable Nontaxable Transaction Certificates to all third-party suppliers of such special tools, materials, and services. The details of the Contractor's responsibility are given in Note 2, which is an addition to Article XX of Form No. 765, Los Alamos Scientific Laboratory Terms and Conditions of Purchase.

c. Payment for these special tools, materials, and services will be made under Item No. 5 of the Unit Price Schedule upon receipt by the University of paid invoices evidencing receipt of such tools, materials, or services by a University representative. No separate payment will be made to cover overhead or profit for this service. Title to all tools and materials purchased by the Contractor pursuant to the direction of the University as provided above, shall pass directly to the Government and all invoices shall so provide.

SC-06. CLEAN UP

The Contractor shall at all times maintain the work site in an orderly manner and free from accumulations of waste material or rubbish. No trash burning, dumping or burying will be permitted on or about the premises of the drilling location or on the adjacent Forest Service land.

SC-07. SITE INVESTIGATIONS AND REPRESENTATIONS

The Contractor acknowledges that he has satisfied himself as to the nature and location of the work; the general and local conditions, particularly those bearing upon transportation, hauling of materials, availability of water, roads and uncertainties of weather, and the physical conditions at the drilling site; the character of equipment and facilities needed preliminary to and during the prosecution of the work; and all other matters upon which information is reasonably obtainable and which can in any way affect the work or the cost thereof under this contract.

SC-08. RECORDS AND OBSERVATIONS

Providing the following records and observations shall be a part of the Contractor's general responsibility for which no additional payment will be made.

A. A Daily Drilling Report shall be kept on a standard AAODC API report form acceptable to the University. The Unit Price Schedule quantities for payment purposes will be taken from the copy of the AAODC Daily Drilling Report delivered each day to a representative of the University.

B. Bit Records will be maintained daily and posted in the dog house. A complete bit record will be furnished to the University showing bit types, footages, depths, serial numbers, and condition when pulled.

C. Accurate Pipe and Bottomhole Assembly Tallies shall be the Contractor's responsibility and shall be available at the drilling site for inspection at all times. Pipe and casing measurements shall be furnished as directed by the University.

SC-09. RESPONSIBILITY FOR LOSS OF OR DAMAGE TO EQUIPMENT

A. Contractor's Surface Equipment. Contractor shall be liable at all times for damage to or destruction of Contractor's surface equipment including all drilling tools, machinery and equipment for use above the surface, and for any other type of equipment including in-hole equipment when such in-hole equipment is above the surface regardless of when or how such damage or destruction occurs. The University shall be under no liability to compensate the Contractor for any such loss except loss or damage thereto caused by negligence of the University, its agents or employees.

B. Loss of Tools in the Hole. When it is necessary to fish for tools in the hole, the Contractor shall initiate such action as is required to commence fishing operations as soon as possible. The Contractor will not be held responsible for costs resulting from the loss of tools or for costs of fishing efforts conducted to recover lost tools, if the Contractor was neither negligent nor in violation of good drilling practice. The value of Contractor-owned tools lost or damaged in the hole will be equitably compensated.

SC-10. LOST HOLE

The hole shall be termed "lost" if the University determines that, due to the condition of the hole or for any other reason, it would be impractical to continue drilling to the minimum required depth of 4500 ft. The University may, at its option, order the commencement of work at an alternate location. In any event, the Contractor will be paid for all work performed under the applicable items of the Unit Price Schedule.

SC-11. ABNORMAL CONDITIONS

Due to the exploratory nature of the work under this Contract, it is not possible to anticipate all the unusual conditions which may be encountered in the drilling of this hole.

PART C-II

TECHNICAL PROVISIONS

TP-01. DRILLING METHOD

A. The hole shall be drilled using rotary drilling methods.

B. While drilling, weight on the bit shall not exceed 80% of the buoyed weight of the drill collars.

C. Circulation methods are to be as described in the Drilling Program (Part C-IV). If hole problems and/or circulating problems are encountered, the University may direct the use of stiff foam, direct circulation using aerated water and/or drilling muds.

D. Tests of blowout preventers.

1. The drill collar and pipe rams shall be closed on the drill pipe once each 24 hours or as requested, while drilling operations are in progress.

2. The blind rams shall be closed on each trip for a new bit.

3. Pressure tests of the entire BOP stack shall be made as follows.

a. Before drilling begins on the 9-5/8-in. hole, the 10-3/4-in. casing and BOP stack shall be tested to 2000 psig. The test pressure must be at least 1850 psig after 10 min.

b. After the shoe has been drilled on the 10-3/4-in.-o.d. casing, the BOP stack shall be tested, using the cup tester, on the first trip with the drill pipe each week. The entire stack shall be tested to 2000 psig and the test pressure must be at least 1900 psig after 10 min. This testing procedure shall be continued until total depth has been reached.

TP-02. CONTRACTOR MINIMUM EQUIPMENT REQUIREMENTS AND STANDARDS

A. Minimum equipment and services required to be furnished and operated by the Contractor at no additional cost to the University are listed in Part C-VI.

B. The following Specifications, Orders and American Petroleum Institute Standards and Recommended Practices, of the latest issue as of the date of bid opening, form a part of these specifications whenever applicable to standardized equipment.

API Std. 4A	Specification for Steel Derricks
API Std. 4E	Specifications for Drilling and Well Servicing Structures
API Std. 7	Specification for Rotary Drilling Equipment
API Std. 8A	Specification for Hoisting Equipment
API Std. 9A	Specification for Wire Rope
API Bull. 10	Procedure for Selecting Rotary Drilling Equipment
API RP-5C1	Recommended Practice for Care and Use of Casing, Drill Pipe and Tubing
API RP-8B	Recommended Practice for Hoisting Tool Inspection and Maintenance Procedures
API RP-9B	Recommended Practice on Application, Care, and Use of Wire Rope for Oil Field Service
API RP-13B	Recommended Practice and Standard Procedures for Testing Drilling Fluids

Title 29 - Labor, Chapter XVII, Part 1910 and 1926 - Occupational Safety and Health Act of 1970.

ASTM E-109	"Dry Powder Magnetic Particle Inspection"
Safety Orders	The State of New Mexico, Department of Oil & Gas

Manufacturer's ratings shall apply for equipment not covered by the API Standards.

TP-03. CIRCULATION FLUID

A. Conductor Hole - (University furnished).

B. Surface Hole - mud.

C. Final Hole - air.

Note: If unexpected hole and/or circulating problems occur, the University or its duly authorized representative may authorize the use of stiff-foam, aerated water with direct circulation, and/or drilling mud as a circulating fluid.

Note: The Contractor shall record the quantities of all chemicals, mud, or special additives used during each tour in the Daily Drilling Report (AAODC).

TP-04. LOGS AND SURVEYS

The logs and surveys which may be run at the direction of the University may include, but are not limited to the following:

1. Gyroscopic direction survey;
2. Caliper log;
3. 3-D;
4. Density log;
5. Temperature log;
6. Induction - electric log;
7. Deviation survey;
8. Core orientation.

TP-05. CASING AND HOLE SIZE

	Hole Size (in.)	Casing Size (in.)	Approximate Depth (ft)
Conductor	26	20	60 (University furnished)
Surface	17-1/2	13-3/8	1000-1600 (if required)
Deep String	12-1/4	10-3/4	2600
Final	9-5/8	None	4500 (option to 6000)

TP-06. INSTALLING CASING

A. Running Casing. Condition of the hole prior to and during the running of the casing shall be the responsibility of the Contractor. The procedure to be followed in handling and running of casing shall conform to accepted API practices and approved methods under present field conditions. Contract casing crews may be used in running each casing string.

B. Cementing Casing. The procedure to be followed in cementing of the casing shall conform to accepted API practices and approved methods under present field conditions.

The cementing services and cementing materials are to be University furnished. All casing strings shall be cemented as directed by the University.

TP-07. ALIGNMENT

The holes shall be checked for deviation by a non-directional survey instrument (TOTCO or equal) run in the drill pipe on wireline or dropped when making a trip. The survey shall be conducted at the final depth in each of the different hole sizes and every 90 ft (±15 ft) while drilling. The maximum rate of change will be under the direct control of the University, and will be minimized commensurate with existing drilling conditions. All surveys shall be witnessed and acknowledged by a representative of the University.

TP-08. SAMPLES, CORES, AND TESTING

A. Samples of cuttings shall be taken during drilling operations at 10-ft intervals unless otherwise directed by the University. The Contractor shall provide all necessary equipment and labor for collecting, packaging, and labeling cuttings samples as a part of his basic obligation under this contract. No separate payments will be made for work performed under this category. Sample containers will be furnished by the University.

B. All cores in the 12-1/4-in. hole are to be cut using a core barrel, 10-1/8-in. core head, and direct circulation using mud as the circulating fluid. Orientation may be requested. The standard packed-hole assembly is to be used above the core barrel assembly during all coring operations, and the cored interval then opened up to a diameter of 12-1/4 in.

C. All cores in the 9-5/8-in. hole are to be cut using a core barrel, button-insert core head, and direct circulation with air.

TP-09. RECORDED MEASUREMENTS

The University will furnish a five-channel rig-floor-mounted recorder to be connected to various sensors on other indicating equipment, to record weight on bit, rpm, circulating fluid flow rate, pressure, etc.

TP-10. CORE ORIENTATION

All cores in the lower continuously cored section of GT-2--the 9-5/8-in. hole from about 2600 ft to TD--will be oriented with equipment furnished by the University. As an option, the cores in the upper section of the hole--the 12-1/4-in. mud-drilled interval above about 2600 ft--will also be oriented.

PART C-III

OBJECTIVES OF THE GT-2 DRILLING PROGRAM

Primary Objective

The primary objective of GT-2 is to verify the suitability of the proposed site for the subsequent two-hole energy extraction experiment, by deep testing of the Precambrian basement rocks in this specific region of the Jemez Plateau. This primary objective will be accomplished in two stages: the first during the actual drilling of GT-2, and the second during a series of post-drilling *in situ* rock mechanics experiments.

A. Drilling-Phase Measurements and Studies

1. The entire section of igneous and metamorphic rock below the Precambrian interface* will be recovered by continuous coring techniques for subsequent petrologic, petrofabric and petrographic studies to determine the suitability of the rock in this area for the proposed pressurized circulation experiment.

2. The *in situ* rock temperature will be measured after the wireline recovery of every other cored section (about every 60 ft), or more often if necessary.

3. The rock thermal conductivity will be measured in the laboratory (and *in situ*, if possible), to allow a determination of the deep-seated heat flow in this region of the Jemez Plateau, and to provide a method of extrapolating the measured rock temperatures to the bottom of the deeper leg of the two-hole circulation experiment (EE-1).

4. The entire drilled interval will be logged, in stages, to obtain diagnostic rock property data (i.e. electrical and sonic properties, density, etc.).

B. Post-Drilling Measurements and Studies (Drilling rig still on location)

1. The fracture orientation (and crack geometry, if possible) will be determined from *in situ* hydraulic fracturing experiments near the bottom of the hole.

2. The required surface pressure levels to both initiate a fracture, and then to extend this fracture out to a radius of a few hundred feet, will be determined by using service company supplied pumping equipment and realistic flow rates (of the order of 10-20 gpm).

3. The fluid leakoff rate from this pressurized fracture zone will be monitored as a function of time, to determine the suitability of this rock to contain the planned pressurized circulation experiments.

Secondary Objectives

An extended series of programmatic-research oriented experiments will be conducted in GT-2 following the completion of the intial post-drilling hydraulic fracturing experiments. Besides a variety of *in situ* rock mechanics, hydrology, heat flow, geophysical and microseismic experiments, GT-2 will be used as a close-in seismic monitoring station for the large-scale hydraulic fracturing operations to be conducted near the bottom of EE-1 following the completion of the drilling operations. (EE-1, the first leg of the two-hole energy extraction experiment, will be located within several hundred yards of GT-2.)

PROGRAM AND EXPERIMENTAL REQUIREMENTS FOR GT-2

Depth of Hole

The depth of GT-2 is specified to be at least 4500 ft--and up to 6000 ft if possible, depending on the actual average drilling rate, drilling problems and costs. The rationale for this specification is as follows: the closer GT-2 is, within reason, to the projected depth for the deeper leg of the subsequent two-hole circulation experiment (7500-9000 ft, depending primarily on the results of GT-2), the more precise will be the extrapolations of temperature, rock structure and fracture suitability.

Coring Program

1. From 60 to 2350 ft (12-1/4-in. hole). The mud-drilled section of hole, above the Precambrian basement rocks (mostly Paleozoic sediments), will be intermittently cored, using a special Smith core bit. A 30-ft core will be cut about every 200 ft, and at formation boundaries. A coring and hole-opening procedure will be necessary because the available chisel-tooth, carbide-insert Smith core bit is 10-1/8 in. Therefore, each cored interval will have to be opened up from 10-1/8 in. to 12-1/4 in.

*Except for the uppermost 250 ft, which will have been drilled with mud at a 12-1/4-in. diameter.

2. Below 2600 ft (9-5/8-in. hole). Continuous coring of the crystalline basement rock below the 10-3/4-in. casing setting depth (from about 2600 ft to TD) is a firm requirement. This specification results from the need to determine, as completely as possible, the variation with depth of:

a. Rock type;

b. Frequency of fractures;

c. Degree and type of fracture cementation;

d. Rock thermal conductivity;

e. Rock permeability.

In Situ Measurements During the Air-Drilling Phase (9-5/8-in. hole)

Following the wireline recovery of each core, a special diagnostic tool will be lowered through the drill pipe on a separate seven-conductor armoured cable, to measure the in situ temperature of the rock at the bottom of the hole. Even though the rock exposed at the bottom of the hole will have been the least disturbed thermally, some significant measuring time (on the order of 30 min) will still be required to reach equilibrium. Self heating of the temperature-measuring thermistor may also be used to measure a relative thermal diffusivity for the rock.

Hole Diameter for the Continuously-Cored Section of GT-2

The Smith Tool Company of Compton, California will manufacture roller-cutter core bits for the GT-2 drilling program. Based on the experience gained from having produced over 150 core bits for the Deep Sea Drilling Program (JOIDES),* they have scaled down this 10-1/8-in. design to produce the necessary core bits for the LASL drilling program. The diameter for this new core bit was set at 9-5/8 inches, to be compatible with available tubular goods, and yet reasonably close to the diameter of the existing core bit design. It is expected that these somewhat smaller diameter bits will perform satisfactorily with no development time.

Casing Sizes

The specified 10-3/4-in. diam for the casing that will be set through the Paleozoic sediments and into the basement crystalline rocks, was determined by the diameter of the continuously cored hole that will be drilled below this casing--9-5/8 inches.

A minimum size of 13-3/8 in. for the surface casing, if needed, is a direct consequence of the diameter of the hole that must be drilled below this casing to set the deeper string of 10-3/4-in. casing.

Drill Pipe Size

The minimum size drill pipe that can be used for the GT-2 drilling program is based on the 3-3/4-in. diam of the inner core barrel used for the wireline recovery of the 2-7/16-in. cores. For adequate clearance, the drill pipe tool joints used for this program must have a minimum i.d. of no less than 4 inches. Therefore, standard 5-1/2 inch, 21.9 lb/ft, Grade E drill pipe or equivalent will be required (with a minimum tool joint i.d. of 4 inches).

Packed Bottomhole Assemblies

For all drilling operations below the 60-ft setting depth for the conductor pipe, a packed--and stabilized--bottomhole assembly will be used to keep the hole as straight as possible, to prevent dog-legs and to extend drill bit life. These bottomhole assemblies--for both the 12-1/4-in. and the 9-5/8-in. drilled holes--will be made as stiff as is reasonably possible. The specific details of these bottomhole assemblies will be discussed later.

PART C-IV

TENTATIVE DRILLING PROGRAM, GT-2

1. Mobilize Rig on Previously Prepared Location. The all-weather road to the location, leveling of the location, and reserve pit will be provided by others.

2. Conductor. The conductor pipe will be set by others prior to mobilization.

a. 26-in. drilled hole to approximately 60 ft (no cellar required).

b. 20-in.-o.d. conductor pipe set plumb at approximately 60 ft with the annulus cemented from the casing point to the surface.

3. Upper Cased Hole.

a. Run and hang 60 ft of 13-3/8-in. H-40 casing within the conductor pipe to act as a centralizer for the subsequent 12-1/4-in. drill hole. The 13-3/8-in. casing should have three equally spaced vertical welded-on centralizer lugs every 20 ft, to

*At only one diameter--10-1/8 in.-- and in a chisel-tooth carbide insert format suitable for drilling in the basaltic rocks underlying the sediments of the ocean floor.

position the 13-3/8-in. casing in the exact center of the 20-in. conductor pipe. (A set of lugs at the top, 20 ft down, 40 ft down, and at the bottom of the 13-3/8-in. casing guide.)

b. Drill a 12-1/4-in. hole with packed-hole drilling assembly until drill collars are buried below bottom of 20-in. conductor. Remove and lay down 13-3/8-in. casing guide from the conductor.

c. Install BOP.

d. Drill a 12-1/4-in. hole to approximately 2600-ft depth using a mud circulating system.

e. Core as directed by the University.

f. Run logs and surveys as directed by the University.

g. Run and set 10-3/4-in. casing at approximately 2600 ft, or as advised by the University. Cement as directed. Install BOP on 10-3/4-in. casing.

Note: If unexpected drilling problems are encountered, ream the 12-1/4-in. hole to 17-1/2 in. in diameter to below trouble zone. Run and set 13-3/8-in. casing through trouble zone. Then continue drilling 12-1/4-in. hole to 2600 ft.

4. Lower Open Hole

a. Continuously core a 9-5/8-in. hole to 4500 ft using air, or drilling fluids as required.

b. Run logs, surveys and tests as directed by the University.

c. As an option, the hole may be continuously cored from 4500 ft to approximately 6000 ft.

d. Conduct hydraulic fracturing and other tests as directed by the University.

PART C-V

UNIVERSITY-FURNISHED ITEMS FOR GT-2

1. Drilling Location; staked, graded, approx 150 ft by 250 ft, with a 200,000 gal reserve pit and a graveled perimeter access road; 60 ft of 20-in. conductor pipe set plumb and cemented to the surface.

2. Access Road; 450 ft of existing Forest Service road, maintained as necessary. (The drilling location is only about 200 yds off State Highway 126--a two-lane paved road that is State-maintained through the winter months.)

3. Casing and Casing Materials

a. Necessary 20-in. o.d., 94 lb/ft, ST&C, H-40 casing.

b. About 1000 to 1600 ft of 13-3/8-in.-o.d., 48-lb/ft, ST&C, H-40 casing (as required).

c. 2120 ft of 10-3/4-in.-o.d., 45.5-lb/ft K-55 buttress-thread casing with 11.25-in. special-clearance couplings.

d. 480 ft of 10-3/4-in., 45.5-lb/ft, K-55 Hydril flush joint casing.

e. Centralizers for 10-3/4-in. casing.

4. Gyroscopic Directional Surveying

5. Air Compressors and Related Equipment; a minimum of 2400 SCFM of air (at 8700-ft altitude) will be provided by using three (or more) primaries and one booster, with a mist pump and appropriate chemicals.

6. Coring Equipment with Integral Stabilization; including an inner core barrel; a 9-5/8-in. hole stabilizer bit sub; an 8-in.-o.d. by 4-1/8-in.-i.d. segmented outer core barrel made up of a 12-ft collar, 9-5/8-in. hole stabilizer sub, 12-ft nonmagnetic collar, latch sub, and upper 9-5/8-in. hole stabilizer cross-over sub; core bits; wireline heads; magnetic surveying and orienting equipment, etc.

7. Cement and cementing services.

8. Mud, chemical additives and mud engineering services.

9. Core Boxes and sample containers.

10. Drill Collars and string stabilizer for coring 9-5/8-in. hole.

a. 56,000 lb (450 ft) of 8-in.-o.d. steel drill collars bored out to an i.d. of 4-1/4 in.

b. One string RWP stabilizer with a 2-ft-long contact length, bored out to an i.d. of 4-1/8 in.

11. Packed-Hole Assembly for 12-1/4-in. hole.

a. 12-1/4-in. six-point bottomhole roller-bit reamer.

b. 12-1/4-in. hole size by 30-ft-long square drill collar.

c. 12-1/4-in. three-point string roller-bit reamer.

d. Upper blade-type string stabilizer.

12. Post-Drilling Fracture Services, including required surface-set openhole packers.

13. Wireline Sheave - standard Schlumberger type wireline.

14. Motor-Generator Sets for University equipment.

15. Swivel - one 150-ton King swivel with a minimum 5-in. bore (to be used during the continuous-coring operations).

16. Split Traveling Block - 150- to 250-ton IDECO dual-speed split traveling block. This traveling block is to be used in conjunction with the King swivel during continuous-coring operations.

17. Elevator Links - 150-ton-capacity elevator links to be used, in place of the customary swivel bail, to position the King swivel below the split traveling block.

18. Drilling Recorder - five-channel electronic strip-chart recorder with remote recording takeoffs.

PART C-VI

MINIMUM EQUIPMENT AND SERVICE REQUIREMENTS TO BE FURNISHED BY THE CONTRACTOR, GT-2

Listed below are the minimum acceptable requirements for the Contractor drilling equipment. This is not intended to be a complete list of items to be furnished by the Contractor. The Contractor is required to furnish all drilling and maintenance tools, materials, and equipment not herein designated, but which are normal components for a complete drilling rig required for drilling and testing operations of the scope of these specifications.

1. Mast or Derrick. Minimum of 440,000 lb gross nominal capacity capable of handling hook loads of 300,000 lb in air with eight lines. Combined racking capacity for 6000 ft of 5-1/2-in. drill pipe and related drill collars. Minimum height of 127 ft.

2. Substructure. Must handle all equipment listed in the derrick specifications and have a minimum setback and rotary table capacity of 250,000 lb. It must accommodate the BOP equipment shown on the drawings (Figs. C-1 and C-2). The substructure minimum overall height should be sufficient to permit the installation of the blow-out preventer equipment listed in Part C-VI, Item 15, without positioning any part of this equipment below ground level.

3. Drawworks. Minimum of 700 horsepower rated input.*

*Note: All engines on drawworks, pumps, light plant, air compressors, water trucks, etc., must be fitted with Forest Service approved mufflers and spark arrestors.

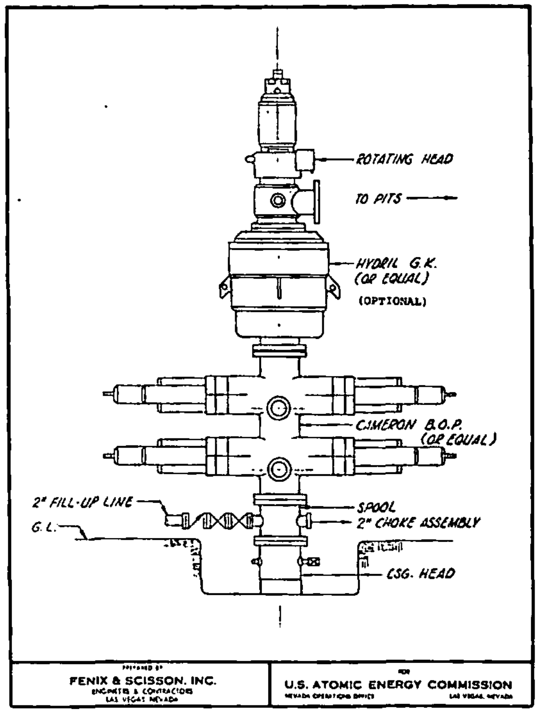


Fig. C-1. Blowout preventer stack for air drilling.

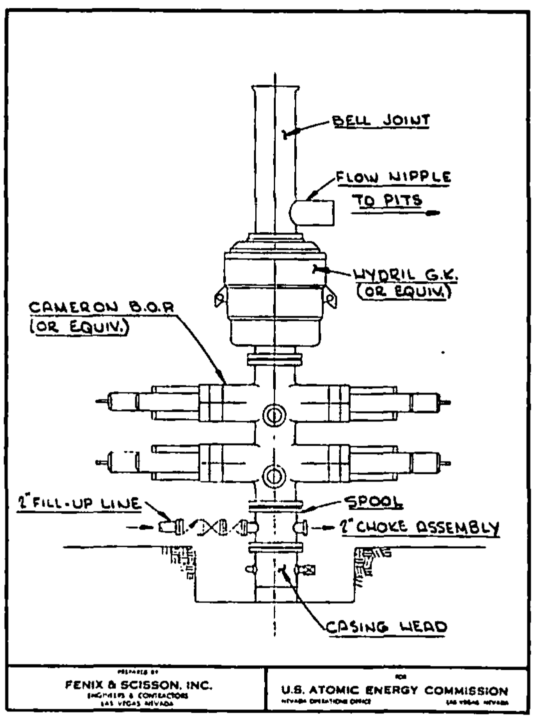


Fig. C-2. Blowout preventer stack for mud drilling.

4. Drawworks Power. Minimum of two prime movers with 850 horsepower continuous rating at 8700 ft above sea level. If the rig is electric, two electric motors are required for the drawworks.

5. Rotary Table - 27-1/2 in.

6. Crown Block - 200 tons.

7. Traveling Block and Hook - 150 tons.

8. Swivel - 150 tons.

9. Drill Line - 65-ton minimum breaking strength.

10. Steel Drill Collars for 12-1/4-in. hole; twelve 9-in.-o.d. drill collars and eight 7-in.-o.d. drill collars.

A magnetic particle inspection on boxes and pins must have been made since the last operation. A copy of the inspection report is to be delivered to the University before drilling operations begin.

11. Drill Pipe. Minimum of 6000 ft of 5-1/2-in., 21.9-lb /ft, Grade E or equivalent, with 5-1/2-in. API couplings. Bore of tool joint couplings must be 4 in. (drift).

All drill pipe is to have been tuboscoped within 30 days prior to the beginning of drilling on this hole and graded tuboscope No. 2 or better with no evidence of fatigue cracks. A copy of the inspection report is to be delivered to the University before drilling operations begin.

12. Stand Pipe. 4-in. minimum i.d. single (including valves). 2-in. minimum i.d. single (including valves) for air injection.

13. Rotary Hoses.

One - 55-ft by 3-in.-i.d., 2500-psi working pressure.
One - 55-ft by 1-1/2-in.-i.d., 100-psi working pressure. (Standby hoses should be available on 12-hour notice.)

14. Mud Pump and Power. Two mud pumps are required each with an output of 600 gpm at 1500-psig discharge pressure at 8700 ft above sea level.

15. Blow-Out Preventer Stack. Shall be designed to operate at a temperature range of -20°F to +300°F (Figs. C-1 and C-2).

a. Hydril Type "GK" or equal, 12-in., Series 900 (3000-psi working pressure), bolted flange type body or equal.

b. Cameron Type "U" or equal, 12-in., Series 900 (3000-psi working pressure, double gate, with blind and pipe rams) or equal.

c. Flanged spool, 12-in. by 12-in., Series 900 (3000-psi working pressure), with two 3-in. flanged side outlets (Fig. C-1).

d. Closing unit, Hydril, Kooney, Payne, or equal, with manual controls located on the floor and at the accumulator. Hydraulic fluid for temperatures of -20°F to +130°F. (Hydril Unit DCEPM-13-K80 and control manifold or equal.)

e. Cameron 12-in. Type "F" cup type tester or equal with drill pipe connection up.

f. Drilling spools for adapting BOP stack to 20-in., 13-3/8-in. if necessary and 10-3/4-in. casing strings.

16. Light Plants. Two 30 kW to supply vapor-proof lighting for rig and rig power requirements.

17. Dog house and trailer house.

18. Catwalk and ramp.

19. Pipe racks. Four sets of steel construction (eight units of 30 ft each).

20. Subs, for all drill pipe, drill collars, bits, and core barrel.

21. Truck, 10-ton tandem, with winch and gin poles to handle Contractor and University furnished equipment at the drilling location.

22. Steel Mud Pits. Three - approximately 6 ft high by 8 ft by 30 ft equipped with 2 jets and 2 mud guns on each unit. Includes all valves and piping.

23. Shale Shaker. Mounted on steel shale pit. Rumba Model 4860-B3 or equal with a No. 16 (1190) screen.

24. Kellys. One 6-in. hexagon by 40 ft with 4-in. i.d., with bushings for 27-1/2-in. table, and all crossover subs.

25. Rotating Head. Shaffer, Grant or equal for air drilling.

26. Choke Manifold. See Fig. C-3.

27. Weight Indicator. Martin Decker Type "FS," or equal.

28. Water Storage. 1000-barrel capacity.

29. Covered Mud Storage. For 250 sacks of bentonite and chemicals.

30. Mouse hole and rat hole liners.

31. Lighting system for rig.

32. Sand line unit with prime mover, or double drum drawworks equipped with 8500 ft of 9/16-in. line. Swab lines must be free of oil.

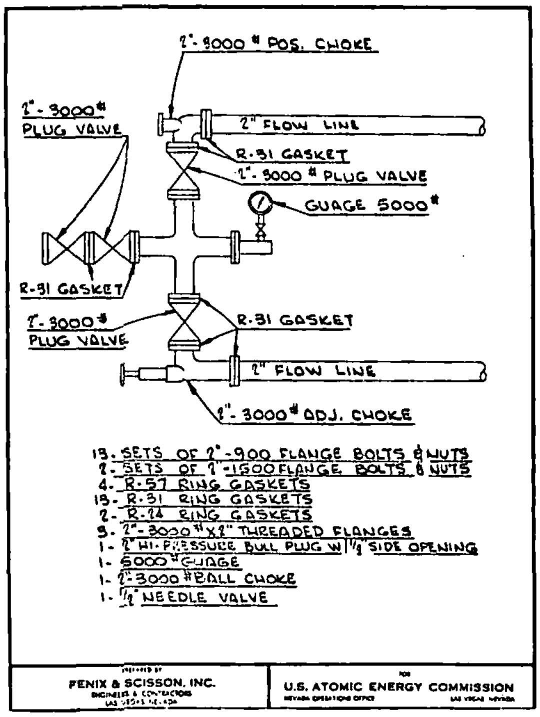


Fig. C-3. Choke manifold.

33. Nondirectional Survey Instrument. TOTCO or equal, 0-7 degrees and 0-14 degrees.

34. Handling Tools, for Contractor- and University-furnished drill collars and drill pipe, 13-3/8-in. and 10-3/4-in. casing. Tools should include tongs, safety clamps, spiders, slips, bails, elevators, wipers, etc.

35. Lubricants for Contractor's equipment.

36. Centrifugal Pump, portable, 1000 gpm against 50-ft water head (2-1/2 in. or 3 in.).

37. Cellar jets or pumps.

38. Hole covers.

39. Welding equipment, one - 250-amp, Lincoln Pipe Line Special, or equal, complete with leads, plus oxy-acetylene cutting equipment and supplies.

40. Mud mixing hopper.

41. Tool joint lubricant (API, 50-60% zinc).

42. Water Transportation for all drilling and cementing requirements. Truck capacity; 2500 gal minimum. Water truck must be capable of self loading and unloading, with a suitable suction pump and 50 ft of large-diameter flexible hose.

43. Chemical Toilet facilities for contractor personnel.

44. Pipe and Fittings for all mud, water and air lines.

45. Fishing Tools for all Contractor-furnished equipment, including a Bowen or equal spiral grapple overshot sized for 9-in.-o.d. drill collars, and a bumper sub.

46. Bracket in Mast or Derrick rated at 50,000 lb load (with safety factor of 3) to support standard Schlumberger wireline sheave.

47. Winterizing Equipment. Windbreaks, heating equipment, windbreaks or shed over mud pumps, steam-boiler, steam lines, etc.

PART C-VII

CONTRACTOR-FURNISHED UNIVERSITY-REIMBURSABLE ITEMS

The equipment and services which the Contractor may be required to furnish and the cost thereof reimbursed under the provisions of Special Items and Services, may include, but are not limited to the following items.

1. Logging and Core Engineering Services.

2. Hydrological Testing Equipment.

3. Casing Heads.

4. Casing Shoes, Float Equipment, and Other Casing Accessories.

5. Water for Drilling and Cementing.

6. Bits, Reamers, and Hole Openers.

7. Casing Crew as required.

8. Fishing Tools for all University equipment, i.e. spiral-grapple overshot, taper tap, bumper sub, mechanical jars, etc.

9. Additional Site Preparation, required to adapt the previously prepared drilling site to a specific drilling rig (no earthen trash pit will be necessary).

10. Trash Removal and Hauling.

11. Fuel for Contractor and University equipment.

PART C-VIII

SUBSURFACE INFORMATION FOR GT-2

These generalized sections are based on the stratigraphic section penetrated in GT-1, 1.5 miles to the north, and are therefore only approximate.*

	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.	275	275
Abiquiu Tuff		
Sandstone, light gray, tuffaceous, friable; mafic minerals and few quartz crystals; rock fragments of pumice, latite, and rhyolite in a fine ash matrix with mafic mineral altered to stain matrix light yellow, 275 to 345 ft. Conglomerate, light gray, tuffaceous, friable with rock fragments of quartzite and chalcedony, 345 to 400 ft.	125	400
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, 400 to 530 ft; sandstone, fine-grained, dark red, 530 to 590 ft; sandstone, fine-grained, alternating with shale, dark red, 590 to 920 ft; shale and sandstone, fine-grained, predominantly red, with lenses of white to gray shale and sandstone, a few thin beds of limestone, 920 to 1270 ft; clay, dark red with minor lenses of shale and sandstone, 1270 to 1310 ft.	910	1310
Magdelena 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, 1310 to 1490 ft; shale, red with some thin lenses of limestone, gray, 1490 to 1570 ft; limestone, gray, with some lenses of sandstone, fine-grained red, and shale, light red, 1570 to 1680 ft; shale dark red, with lenses of limestone, dark gray, 1680 to 1770 ft; limestone, gray, with thin lenses of light red, and gray limestone, fine-grained, 1770 to 1900 ft.	590	1900
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	2055

*Adapted from LA-5124-MS, "Geology of the Jemez Plateau West of the Valles Caldera," W. D. Purtymun (Feb 1973).

	Thickness (ft)	Depth (ft)
Sandia Formation		
Upper clastic member, limestone, gray with lenses of gray shale and fine-grained sandstone ranging from light gray to light green.	235	2290
Lower limestone member, limestone, dark gray, siliceous, dense.	60	2350
Precambrian Rocks		
Augen gneiss, brownish gray, with inclusions of pink plagioclase; granite, reddish brown, medium-grained, foliated; amphibolite, dark gray, fine-grained, and other granitic and metamorphic rocks.	> 2150	> 4500

PART C-IX

UNIT PRICE SCHEDULE

for

Geothermal Test Hole No. 2
(GT-2)

Item Number	Description	Estimated Quantity	Unit	Unit Price	Estimated Amount
1.	Mobilization	1	Job	$______	$______
2.	Hourly Rate Operations				
	a. With Drill Pipe	1176	Hr.	$______	$______
	b. Without Drill Pipe	192	Hr.	$______	$______
3.	Standby-Secured	0	Hr.	$______	$______
4.	Demobilization	1	Job	$______	$______
5.	Special Items and Services		Dollars	$______	$58,000.00
	TOTALS	(57 days)			$______

APPENDIX D

SPECIFICATIONS OF CALVERT WESTERN EXPLORATION COMPANY

DRILLING RIG NO. 24

Brewster Model N-7, rated 2896 m with 12.7-cm-diam drill pipe; drawworks power: two Waukesha diesel engines, 820 kW intermittent; 1.02-m double hydramatic brake, capable of handling 125 Mg; main mud pump: 20-cm by 41-cm Bethlehem 485 kW; auxiliary pump: 18-cm by 41-cm, rated 373 kW; mast: 40-m Lee C. Moore, 250-Mg capacity; substructure: 283-Mg capacity; Shaeffer 30-cm double hydraulic blowout preventer; drill: 14 cm; completely winterized with forced air heating system.

(Brewster Model N-7, rated 9500 ft with 5-in.-diam drill pipe; drawworks horsepower: two Waukesha diesel 1100 intermittent hp; 40-in. double hydramatic brake; capable of handling 275,000 lb ; main mud pump: 8-in. by 16-in. Bethlehem 650 input hp; auxiliary pump: 7-1/4-in. by 16-in., rated 500 hp; mast: 131-ft Lee C. Moore, 550,000 lb GNC; substructure: 625,000-lb capacity; Shaffer 12-in. double hydraulic blowout preventer; drill: 5-1/2 in.; completely winterized with forced-air heating system.)

APPENDIX E

BIT RECORD

COMPANY LASL | CONTRACTOR Calvert Western | COUNTY Sandoval | STATE New Mexico

LEASE GT-2 | WELL NO 2 | SEC. | TOWNSHIP | RANGE | BLOCK | FIELD

TOOL PUSHER Ray England | DRILL PIPE 5-1/2 | DRAW WORKS N-7

DAY DRILLER | TOOL JOINT MAKE SIZE TYPE | POWER LRD H.P 1100 | UNDER SURF

EVENING DRILLER | DRILL COLLAR NO 15 O D 8 I D 4 LENGTH 450 | PUMP NO. 1 MAKE G6S MODEL Beth STROKE 16 | INT. DATE

MORNING DRILLER | DRILL COLLAR NO O D I D LENGTH | PUMP NO 2 MAKE G450 MODEL Beth STROKE 16 | T.D. DATE

BIT NO	BIT SIZE	BIT MFGR	BIT TYPE	SERIAL NO OF BIT	JET SIZE			DEPTH OUT	FTGE	HOURS RUN	ACC HOURS	FT/HR	WEIGHT 1000 LBS.	ROTARY R.P.M	VERT. DEV.	PUMP PRESS	PUMPS			MUD		DULL CODE			REMARKS FORMATION, CIRC. FLUID, ETC.	DATE
					1	2	3										No.	Liner	SPM	Wt	Vis	T	B	G		
RR	15		053A		10	10	10	73	73																Rerun bit	
RR	26		HO					73	73																Rerun bit	
1	12¼	STC	3JS	ML085	13	13	13	645	582	38			25	65		500	1	5	65							
2	12¼	STC	V2J	RJ324	13	13	13	1204	559	26½			40	65		500										
3	12¼	HTC	ODV	WN943	14	14	14	1466	262	23-3/4			40	60		500										
4	12¼	Sec	MAN	498160	12	12	12	1664	198				40	60		500										
5	12¼	Sec	M88	477840	12	12	12	1916	252	35½																
6	12¼	HTC	ODV	MU614	out								Drill cement-wash to bottom													
1HO	17½	STC	HO	3P446				673	593	39½			20/40	45/65		300		5	65						Hole-opener bit	
2HO	17½	STC	HO	3P278				1451	778	52½			20/40	45/65		300									Hole-opener bit	
3HO	17½	STC	HO	3P317				1605	154	14			20/	45/65		300									Hole-opener bit	
6	12¼	HTC	ODV	MU416	out			2078	172				15	33		100		air							Rerun bit	
7	12¼	STC	7JS	NB034	out			2536	458	12								air/mud								
8	9-5/8	STC	9JS	AP649	out			2547	11	2								air								
2	9-5/8	STC	98CJ	A/RN282	12	12	12	2590	33																Core bit	
3	9-5/8	STC	98CJ	A/RN281	12	12	12	2605	15																Core bit	
8	9-5/8	STC	9JS	PP649	out			2842	237	38								air				5	4	3/16	Rerun bit	
9	9-5/8	STC	9JS	AP783	out			2842	ream																	
4	9-5/8	STC	98CJ	A/RN278	12	12	12	2886																	Core bit	
9	9-5/8	STC	9JS	AP783	out			3147	290	27	27														Rerun bit	
5	9-5/8	STC	98CJ	A/RB311	12	12	12	3182	35	5															Core bit	

SMITH REPRESENTATIVE ____________ PHONE ________

Fig. E-1. Drill bit record to 880-m depth (2886 ft).

BIT RECORD

COMPANY: LASL (Continued) #2 | CONTRACTOR: Calvert Western | COUNTY: Sandoval | STATE: New Mexico

LEASE: GT-2 | WELL NO.: 2 | SEC | TOWNSHIP | RANGE | BLOCK | FIELD

TOOL PUSHER: Ray England | DRILL PIPE: 5-1/2 | DRAW WORKS: N-7

DAY DRILLER | TOOL JOINT: MAKE, SIZE, TYPE | POWER: LRD | H.P: 1100 | UNDER SURF

EVENING DRILLER | DRILL COLLAR: NO 15, O D 8, I D 4, LENGTH 450 | PUMP NO. 1: MAKE G6S, MODEL Beth, STROKE 16 | INT DATE

MORNING DRILLER | DRILL COLLAR: NO, O D, I D, LENGTH | PUMP NO 2: MAKE G450, MODEL Beth, STROKE 16 | T.D. DATE

BIT NO	BIT SIZE	BIT MFGR	BIT TYPE	SERIAL NO OF BIT	JET SIZE 1	JET SIZE 2	JET SIZE 3	DEPTH OUT	FTGE	HOURS RUN	ACC HOURS	FT/HR	WEIGHT 1000 LBS.	ROTARY R.P.M	VERT DEV.	PUMP PRESS	PUMPS No.	PUMPS Liner	PUMPS SPM	MUD Wt	MUD Vis.	DULL CODE T	DULL CODE B	DULL CODE G	REMARKS FORMATION, CIRC. FLUID, ETC.	DATE
10	9-5/8	STC	9JS	AP718		out		3463	281	32½								air								
11	9-5/8	HTC	RG2BJ	MC409		out		ream																		
6	9-5/8	STC	98CJA	RN283	12	12	12	3476	13	3½					1¼										Core bit	
12	9-5/8	STC	9JS	AP775		out		3542	66	8																
13	9-5/8	STC	SV2	60431		out		drilling bridge plug																		
11	9-5/8	HTC	RG2B	MC409		out		drilling bridge plug																	Rerun bit	
14	9-1/2	STC	SL4	HN620		out		drilling bridge plug																		
12	9-5/8	STC	9JS	AP775		out		drilling cement																		
15	9-5/8	STC	9JS	AU848		out		drilling cement																		
16	9-5/8	STC	9JS	AP646		out		3666	110	15½																
17	9-1/2	STC	SWC	NE704		out		cement retainer																		
16	9-5/8	STC	9JS	AP646		out		3693	27	7															Rerun bit	
1	9-5/8	CDP	◊	MC201				3705	12	16½															Core bit	
18	9-5/8	STC	9JS	AP580		out		3728	23	4½																
19	8-1/2	Varel	V2	96524		reg		drilling cement in drill pipe																		
18	9-5/8	STC	9JS	AP580		out		3822	98	18												7	8		Rerun bit	
20	9-5/8	STC	9JS	AP720		out		4021	199	39			45	35				air				5	6	1/16		
21	9-5/8	STC	9JS	AP784		out		4278	257	42			45	35				water				5	6	1/16		
2	9-5/8	CDP	◊	4527360				4279	6	6															Core bit	
22	9-5/8	STC	9JS	AP597	16	16	16	4556	277	49½			45	44		650	1	6"	62			4	4	¼		
23	9-5/8	STC	9JS	AP586	16	16	16	4835	279	60½			45	44		650	1	6"	62			6	5	½		

SMITH REPRESENTATIVE ____________________ PHONE __________

Fig. E-2. Drill bit record to 1304-m depth (4279 ft).

50:481(310)

BIT RECORD

Field	Entry
COMPANY	LASL (Continued) #3
CONTRACTOR	Calvert Western
COUNTY	Sandoval
STATE	New Mexico
LEASE	GT-2
WELL NO.	2
SEC.	
TOWNSHIP	
RANGE	
BLOCK	
FIELD	
TOOL PUSHER	Ray England
DRILL PIPE	5-1/2
DRAW-WORKS	N-7
DAY DRILLER	
TOOL JOINT — MAKE / SIZE / TYPE	
POWER	LRD
H.P	1100
UNDER SURF.	
EVENING DRILLER	
DRILL COLLAR — NO / O.D / I D / LENGTH	15 / 8 / 4 / 450
PUMP NO. 1 — MAKE / MODEL / STROKE	G6S / Beth / 16
INT. DATE	
MORNING DRILLER	
DRILL COLLAR — NO / O.D / I D / LENGTH	
PUMP NO 2 — MAKE / MODEL / STROKE	G450 / Beth / 16
T.D. DATE	

BIT NO	BIT SIZE	BIT MFGR	BIT TYPE	SERIAL NO OF BIT	JET SIZE 1	2	3	DEPTH OUT	FTGE	HOURS RUN	ACC HOURS	FT/HR	WEIGHT 1000 LBS.	ROTARY R.P M	VERT. DEV.	PUMP PRESS	PUMPS No.	Liner	SPM	MUD Wt.	Vis.	DULL CODE T	B	G	REMARKS FORMATION, CIRC. FLUID, ETC.	DATE
24	9-5/8	STC	9JS	AP560	16	16	16	4892	57	10½			45	44		650	1	6"	62			1	1	¼		
2	9-5/8	CDP		4527360				4897	5	6½			25/30	42		800	1	6"	52						Rerun core bit	
24	9-5/8	STC	9JS	AP560	16	16	16	4915	18	4			45	44		650	1	6"	62						Rerun bit	
6	9-5/8	STC	98CJ	A/RR310	12	12	12	4921	6	2			25	36		250	1	6"	62						Rerun core bit	
25	9-5/8	STC	9JS	AP639	16	16	16	5234	313	65			45	44		650	1	6"	62	85	34	8	7	¼		
6	9-5/8	STC	98CJ	A/RR310	12	12	12	5240	6	3			20	40		650	1	6"	56	86	35				Rerun core bit	
26	9-5/8	STC	9JS	AP785	16	16	16	5479	239	51			45	42		600	1	6"	62	86	33	7	8	¼		
24	9-5/8	STC	9JS	AP560	16	16	16	5487	8	2			45	42		600	1	6"	62	86	33				Rerun bit	
2	9-5/8	CDP		4527360				5492	5	5			32	44		650	2	5¼"	56	86	32				Rerun core bit	
27	9-5/8	STC	9JS	AP666	16	16	16	5654	162	27½			40	42		650	1	6"	62	86	33	7	7	1/16		
6	9-5/8	STC	98CJ	A/RR310	12	12	12	5669	15	3½			30	38		350	1	6"	56	86	33				Rerun core bit	
28	9-5/8	STC	9JS	AP648	16	16	16	5979	310	56½			40	42		700	1	6"	62	86	34					
7	9-5/8	STC	98CJ	A/RN277	12	12	12	5986	7	3			25	34		450	2	5¼"	56	86	33					
24	9-5/8	STC	9JS	AP560	16	16	16	6150	164	18½			40	42		650	1	6"	62	85	32				Rerun bit	
7	9-5/8	STC	98CJ	A/RN277	12	12	12	6162	12	3			25	34		450	2	5¼"	56	86	33				Rerun core bit	
29	9-5/8	STC	9JS	AP721	16	16	16	6344	182	32			40	42		650	1	6"	62	86	33					
7	9-5/8	STC	98CJ	A/RN277	12	12	12	6350	6	1½			30	30		450	2	5¼"	56	86	33				Rerun core bit	
8	9-5/8	STC	98CJ	A/RR312	12	12	12	6356	6	1½			30	30		450	2	5¼"	56	86	34					

SMITH REPRESENTATIVE ______________________ PHONE ____________

Fig. E-3. Drill bit record to 1937-m depth (6356 ft).