502
9-20-77

LA-6906-MS

Informal Report

UC-66c

Issued: August 1977

LB. 1422

MASTER

Planning, Drilling, Logging, and Testing of Energy Extraction Hole EE-1, Phases I and II

Roland A. Pettitt

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

An Affirmative Action/Equal Opportunity Employer

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America. Available from
National Technical Information Service

U.S. Department of Commerce

5285 Port Royal Road

Springfield, VA 22161

Price: Printed Copy ~~\$4.00~~ Microfiche \$3.00
5.05

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

PLANNING, DRILLING, LOGGING, AND TESTING
OF ENERGY EXTRACTION HOLE EE-1, PHASES I AND II

by

Roland A. Pettitt

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ABSTRACT

Energy Extraction Hole No. 1 (EE-1) is the second deep hole drilled into the Precambrian-age granitic rocks of the Jemez Mountains of north-central New Mexico. EE-1 was drilled to intersect a hydraulic fracture extending outward from near the bottom of previously drilled hole GT-2, thus completing the underground circulation loop required for the hot dry rock geothermal energy extraction experiment. Directional drilling techniques were used to intersect the fracture zone. In addition, high-temperature instrumentation and equipment development, hydraulic fracturing experiments, pressure-flow testing of the fracture systems, and fracture mapping and borehole-ranging technique activities were conducted. This report describes the drilling, logging, and testing operations in EE-1.

I. INTRODUCTION

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 also be to make this new technology available to industry as soon as its usefulness has been demonstrated.

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). As a result of 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 Fitzsimmons⁹ described some of the Precambrian rocks in the area, and West¹⁰ has discussed the geophysics of the Jemez Mountains.

Fig. 1.

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

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 area. On the basis of previous studies, surveys, and field experiments,¹¹⁻¹³ a specific site on the Jemez Plateau west of Los Alamos was selected as an appropriate location for development of the first hot dry rock energy experiment (Fig. 2). It has been officially identified as the "Fenton Hill Site," or TA-57 (LASL Technical Area 57).

Fig. 2.

Aerial view of the Fenton Hill site looking northeast. The clear area in the center, left of the highway, is the site of the drilling operation.

This report presents a chronological history of the work done and the problems encountered in drilling, logging, installing casing, and testing in EE-1, Phases I and II.

II. SUMMARY OF PRECEDING WORK

Geothermal Test Hole No. 2 (GT-2) was the first deep exploratory hole drilled to confirm the suitability of the Fenton Hill site for further development of the hot dry rock geothermal energy experiment. Drilling began in GT-2 on February 17, 1974, and was completed to a depth of 2042.6 m (6701.5 ft) in September 1974. The hole was cased with 27.3-cm- (10-3/4-in.-) diam casing from the surface to a depth of 773 m (2535 ft), which was 40 m (131 ft) into the Precambrian granitic basement rock.

A series of hydraulic fracturing tests, conducted at specific depths in the granitic section of the hole, was completed in early October 1974. Following this work, the hole was deepened to 2932 m (9619 ft). Various diagnostic logging operations were performed after the drilling was completed. A 185-m- (608-ft-) long liner assembly with a polished-bore receptacle at its upper end, was then placed and cemented in the bottom section of the hole.

Detailed accounts of the planning, drilling, logging, and testing work performed in GT-2 have been presented in previous reports.¹⁴⁻²⁰

III. SITE PREPARATION

A. Location

The site for drilling EE-1 was located 76.8 m (252 ft) approximately N14°E (true) of GT-2 (Fig. 3). As a result of the earlier hydraulic fracturing experiments and impression packer tests, a fracture was thought to exist in the bottom of GT-2 with an azimuth of N35°E. From information derived from deviation and directional surveys, the bottom of GT-2 was calculated to be offset about 110 m (360 ft) to the northwest of the top of the hole. Thus the actual ground location selected for EE-1 was thought to be southeast of the fracture extending from GT-2. The interception of the fracture by EE-1 was planned to be accomplished by directional drilling into the fracture from the side.

The location of this particular site for EE-1 required a minimum of grading and no cutting of standing timber. It was located within the area previously approved by the Forest Service for the demonstration project.¹⁵

B. Work

A contract for the preparation of the EE-1 drilling site was let to C. J. C., Inc., General Contractors, Jemez Springs, New Mexico. Snow and stump removal began on April 10; excavation and grading continued through the month as the weather permitted. The major work consisted of leveling an area for the drilling rig, and excavation and embankment for a 140-m³ (300 000-gal) settling pond.

IV. DRILLING HISTORY

A. Contractual Agreements

More than 40 separate contracts were issued to cover the drilling and associated work at the EE-1 site. The major contracts are listed and described below.

1. Drilling Contracts

a. Preparatory Work. The first drilling at the EE-1 site began on May 8. A 3-m-deep, 1.2-m-diam (10-ft-deep, 4-ft-diam) hole for the conductor casing was drilled by Permian Foundation and Drilling Company of Hobbs, New Mexico, with a truck-mounted auger (Fig. 4). The 0.76-m- (30-in.-) diam corrugated metal pipe (CMP) conductor casing was subsequently cemented in place on May 12.

On May 16, a 5.5-m- (18-ft-) deep "mouse" hole and an 8.2-m- (27-ft-) deep "rat" hole were drilled by the L & B Speed Drill Company of Farmington, New Mexico.

b. Major Drilling Contract. In March and April, bids were solicited from nine drilling contractors for the work described in the specifications listed in Appendix A. Four of the contractors responded and submitted bids; Signal Drilling Company of Denver, Colorado, was the low bidder meeting the terms and conditions of the specifications. On May 9, a letter of intent was sent to Signal Drilling who began preparations to move a drilling rig to Fenton Hill.

The specifications of the drilling rig are listed in Appendix B.

c. Contract Items. The contract with Signal Drilling Company contained six major items: mobilization, hourly rate operations with drill pipe and without drill pipe, standby-secured, demobilization (lump sum), optional demobilization hourly rate operations, and special items and services.

The contract provided for 180 days of drilling, and the hole was completed within the specified time. Owing to programmatic changes, however, EE-1 was terminated at a shallower depth than specified in Appendix A.

Fig. 3.
Aerial view of TA-57, showing GT-2 on the left and EE-1 in the center.

Fig. 4.
Installing corrugated metal pipe conductor casing.

d. Third-Party Contracts. The contract item for Special Items and Services provided for the procurement of reimbursable (seller-acquired) items and services under a "third-party agreement." Typical services which were furnished the drilling contractor under this item included cementing, fishing, logging, welding, casing setting, bits, packers, retainers, diesel fuel, butane, drilling mud and lost-circulation material, and directional-drilling equipment and services.

2. Mud Services. Although almost all of the drilling mud materials were supplied under a third-party contract, a purchase order contract was let to Baroid Division, N L Industries, Inc., Farmington, New Mexico. The contract provided for the services of a mud engineer, available 24 h/day, including all required mud testing equipment and apparatus. The original purchase order provided for 10 days of services and was extended for 14 days.

3. Cementing Services. A contract for casing cementing services was awarded to Byron Jackson, Inc., Farmington, New Mexico. The contract covered the cementing of the first two casing strings: 182.9 m (600 ft) of 50.8-cm- (20-in.-) o.d. line pipe in a 66-cm- (26-in.-) diam hole, and 792.5 m (2600 ft) of 34-cm-o.d. casing in a 44.5-cm- (17.5-in.-) diam hole. The specifications for these cementing services are listed in Appendix C.

4. Drill Bits, Reamers, and Cutters. Purchase order contracts were awarded to a number of suppliers for the drill bits, and the reamer and cutter assemblies used in EE-1. The major suppliers were the Security Oil Field Products Division of Dresser Industries and Smith Tool Division of Smith International, Inc. for tricone rock bits, Christensen Diamond Products and American Coldset Corporation for diamond core bits, and Drilco Division of Smith International, Inc., for 3- and 6-point reamer-cutter assemblies and carbide insert replacement cutters.

5. Road and Site Maintenance. A contract was let to C. J. C., Inc., General Contractors, Jemez Springs, New Mexico to provide necessary site and road maintenance, snow removal, and water supply for drilling operations and experiments. This work also included performing various maintenance and small construction operations in all of the TA-57 area, including the previously completed hole GT-2.

B. Drilling Progress

1. Mobilization. On May 16, Signal Drilling Company began moving the equipment for Drilling Rig No. 5 onto the location. The substructure was placed on May 21, and erection of the drilling rig was completed on May 25 (Fig. 5).

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.

Two tool pushers were employed, each being on duty at the drill site for alternating 24-h periods. One of these men was the Superintendent for the job; the other acted as Assistant Superintendent. A third tool pusher was also employed by the contractor and he served as a cost expeditor. A combination office and sleeping trailer was positioned near the drilling rig for the tool pushers' use.

The elevation of the top of the Kelly bushing was 2655.2 m (8711.3 ft) above the mean sea level, and all depths in this report were measured from that point.

Drilling operations in EE-1 were conducted in two phases as described.

<u>Phase</u>	<u>Starting Date</u>	<u>Final Depth</u>
I	May 26, 1975	2099 m (6886 ft)
II	August 31, 1975	3064 m (10 053 ft)

Fig. 5.
Drilling rig on location over Hole EE-1 at the Fenton Hill site.

2. Volcanic Rock. At 1:00 p.m. on May 26, drilling began in the volcanic tuff rock below the conductor casing, using a 44.5-cm- (17.5-in.-) diam tricone rock bit. Minor problems were encountered with leakage of drilling mud around the conductor casing, the mouse hole, and the rat hole. Although lost-circulation material was mixed with the drilling mud, these problems continued until the first string of casing was set. The average drilling rate varied from 9 to 18 m/h (30 to 60 ft/h).

3. Sedimentary Rocks. The Abo Formation (Permian red beds) was encountered at a depth of 137 m (450 ft) on May 28. Drilling of the pilot hole continued to a depth of 182.6 m (599 ft); the hole was then reamed to 178 m

(584 ft) with a 66-cm- (26-in.-) diam hole-opening bit. The 50.8-cm- (20-in.-) diam casing was set on June 2 to a depth of 176.9 m (580.3 ft). Drilling below the casing continued using 44.5-cm- (17.5-in.-) diam carbide-insert and steel-toothed rock bits. On June 7, the Madera Formation (Pennsylvanian shales and limestones) was entered. The average drilling rate in the Abo Formation varied from 4 to 8 m/h (13 to 26 ft/h) with a weight of approximately 31.8 Mg (70 000 lbs) being maintained on the bit. Penetration rates in the Madera Formation varied from 1 to 3 m/h (3 to 10 ft/h) with a bit weight of 27.3 Mg (60 000 lbs).

On June 12, at a depth of 579 m (1900 ft), lost-circulation material was added to the drilling mud in preparation for the anticipated problems in the cavernous zone in the Madera Formation encountered in GT-2. At a depth of 581 m (1905 ft), all circulation was lost and the drill pipe became stuck. After several hours, the pipe was freed and pulled from the hole. The jets were removed from the bit and the string was started back down the hole while 30% lost-circulation material was being added to the mud pits. Drilling then progressed satisfactorily, with continual additions of cottonseed hulls, Fibertex, and Gelflake to the drilling mud until, at a depth of 719 m (2359 ft), circulation was again lost and the drill pipe became stuck.

Efforts to restore circulation and free the stuck pipe continued for 2 days. Five pills of 111 m³ each (700 bbl) containing up to 40% lost-circulation material were pumped down the hole without success, and fishing services were called from Farmington, New Mexico. GO-International Logging determined the "free point" of the pipe string to be 24.4 m (80 ft) off bottom. An explosive string shot was detonated at a pipe joint 33.5 m (110 ft) off bottom, and that joint broke loose. All the pipe was withdrawn from the hole, except the bottom 33.5 m (110 ft), by 5:30 a.m. on June 21. In washing and drilling down to fish out the pipe at the bottom of the hole, numerous bridges were encountered and lost circulation problems continued.

All of the pipe was finally recovered on June 24, but as circulation returns were not established, plans were made to cement the hole. The next day, two 100-sack batches of cement containing bentonite and Gelflake were pumped down the hole through open-ended drill pipe by Byron-Jackson Company of Farmington (Fig. 6) but no fillup was achieved. A "gunk" squeeze cement mixture of bentonite, cement, and diesel oil also proved ineffective. On June 26, a 100-sack batch of cement with Cello-Flake and 3% calcium chloride appeared to

Fig. 6.

Cementing truck hookup during cementing of EE-1 casing.

seal off the lost-circulation zone. After drilling through the cement plug and 0.3 m (1 ft) into fresh limestone at the bottom of the hole, circulation was again lost. As circulation was also being lost through two zones higher in the hole, which hampered drilling down through the numerous bridges, two plugs of 100-sacks each of cement were set at depths of 579 m (1900 ft) and 640 m (2100 ft). After stabilizing these sections of the hole, additional water-hauling trucks were engaged and plans were made to drill ahead without returns.

The granite surface was reached on July 2 at a depth of 731.8 m (2401 ft). The drilling rate in the limestone was 4.3 m/h (14 ft/h), but decreased to 1.3 m/h (4 ft/h) in the granite. Drilling without returns continued to a depth of 741 m (2431 ft), the hole was cleaned and 34-cm- (13-3/8-in.-) diam casing was set to full depth on July 4.

Considerable difficulty was experienced in cementing the casing and eventually the top and bottom sections were cemented separately. The cementing operation is described fully in Sec. V, CASING.

On July 7, when redrilling down through the cementing collars, all circulation was again lost when the bit reached the bottom of the hole. The bottom of the casing was then cemented through open-ended drill pipe with a slurry containing calcium chloride and Cello-Flake. When this plug was drilled through, a full return of the drilling fluid was maintained and drilling in the granitic rock continued.

Maximum hole deviation in the sedimentary beds was 1-1/2 degrees from the vertical.

4. Granitic Basement. Drilling below the casing in the granitic rock began with a Smith Q-9, 31.1-cm- (12-1/4-in.-)diam full-face rock bit. The initial penetration rate was 1.2 m/h (4 ft/h) with a weight of 18.1 Mg (40 000 lbs) on the bit, and with full returns of the drilling fluid. A survey at a depth of 765 m (2509 ft) indicated a deviation of 3/4 degree from the vertical and a hole direction of N52°W (true).

The first bit change in the granitic basement occurred at a depth of 849 m (2785 ft) after drilling 108 m (354 ft) in 71 h. Two of the three bearings were nearly immovable, four buttons were missing, but the bit was still in gauge. During the drilling interval, the average rotational speed was 44 rpm, and the weight on the bit had been gradually increased to 29.5 Mg (65 000 lbs). Drilling continued, alternating between Smith Q-9J bits and Security 100 bits, as shown on the drill bit record (Appendix D). The first Security bit drilled 198 m (650 ft) in 107.5 h. When pulled, it was 1 cm (3/8 in.) under gauge, and had approximately one-third of its buttons missing.

At a depth of about 1006 m (3350 ft), the drilling fluid loss was about 5.6 m³/h (35 bbl/h). This amount gradually decreased to 0.8 m³/h (5 bbl/h) at a depth of 1158 m (3800 ft). No increase in fluid loss was experienced while drilling through the 1097- to 1128-m (3600- to 3700-ft) depth, which was the interval of severe fluid loss in GT-2. By that depth, the hole deviation had gradually increased to 2 degrees from the vertical, with the direction assuming a nearly constant azimuth of N75°W (true). Drilling progressed smoothly at the average rate of about 52 m/day (170 ft) until August 5 when, at a depth of 1824 m (5985 ft), the penetration rate suddenly increased from 1.8 m/h (6 ft/h) to 5.8 m/h (19 ft/h). It had been previously planned to case the hole to a depth of 1920 m (6300 ft), but the increased penetration rate caused concern regarding the quality of the rock below the planned casing setting depth. The decision was made to drill to at least 1957 m (6420 ft)

before setting the casing. The zone of high-penetration drilling actually ended at 1902 m (6240 ft), and the penetration rate decreased to 3 m/h (10 ft/h). Drilling was carried on to the 1957-m (6420-ft) depth, the hole was circulated for 3 h and the drill string pulled. A suite of logs was run by a commercial logging company; on August 13 the 27.3-cm- (10-3/4-in.-) diam casing was set to full depth and the bottom 305 m (1000 ft) was cemented.

After waiting 18 h for the cement to set, the hole was entered with a 25.1-cm- (9-7/8-in.-) diam Security H-10 tricone rock bit. At a depth of 2095 m (6874 ft), the bit was pulled after drilling 138 m (454 ft) in 50 h and a 3.7-m (12-ft) coring run was made with a JOIDES core bit.

A series of logging and cementing operations, fracture, pumping, and impression packer tests was conducted in the bottom section of the hole over the next 10 days, with drilling being resumed again on August 31.

During drilling operations below 1120 m (3700 ft), the inclination of the hole had gradually increased to about 6 degrees from the vertical. This deviation placed the bottom of the hole on the northwest side of the fracture which was thought to extend northeast from the bottom of GT-2. To intercept the fracture, the hole had to be angled back to the southwest. However, information from the last fracture and impression packer tests in EE-1 at about 1966 m (6450 ft) indicated that the fracture in GT-2 was more likely oriented in a NW-SE direction rather than the previously indicated NE-SW direction. Because of the relative uncertainty of the position of the GT-2 fracture, the decision was made to drill EE-1 so that it would pass within 15 m (50 ft) of the bottom of GT-2, thus having a good probability of intersecting the fracture regardless of its orientation. Arrangements were made to conduct directional drilling operations using a Dyna-Drill assembly.

The first Dyna-Drill run, on August 31, started at 2099 m (6886 ft), and marked the beginning of Phase II. This drilling run was 20 m (65 ft) long and turned the hole to a direction of S81°W (true) with an inclination of 5-1/2 degrees from the vertical. Normal drilling was then resumed with a full-face bit for an additional 25 m (82 ft). At a depth of 2144 m (7033 ft), the direction was S70°W with a deviation of 6 degrees. At that depth, the hole had been turned a total of 43 degrees, marking the first time that directional drilling had been accomplished in hot granitic rock.

Directional drilling continued, gradually turning the hole toward GT-2. Figure 7 shows the path taken in the subsequent directional drilling. This map

Fig. 7.

Plan view of directional drilling in GT-2 and EE-1. Depths, in feet, measured from elevation taken at casing flange near ground level.

of the drill hole trajectories was based upon magnetic surveys made during the drilling operations, and was later discovered to be somewhat in error. (Note that depths in the figure are measured from the casing flange, about 4-1/2 m (15 ft) below the Kelly bushing.) The Scientific Drilling Controls device was used for directing and checking the course.

At a depth of 2388 m (7936 ft), a drilling fluid loss of approximately $9.5 \text{ m}^3/\text{h}$ (60 bbls/h) was encountered. On September 13, two pills of paper pulp and walnut shells were pumped down the hole without diminishing the loss. A series of acoustic-ranging measurements conducted on September 20 (see Sec. XII,B) between the two holes indicated that at 2764 m (9070 ft), the holes were about 16 m (52 ft) apart horizontally. At that time, the decision was made to drill directly under the bottom of GT-2 at a depth of 2995 m (9825 ft) at a 10 to 11° angle of inclination.

Another series of acoustic-ranging measurements was conducted between the two holes from September 24 to October 1. The position of EE-1 at a depth of 2914 m (9560 ft) was determined to be approximately 8 m (26 ft) away from GT-2 in a nearly due west direction. (It was subsequently determined that this distance was about right, but that the direction was wrong.)

When directional drilling was resumed on October 1, the azimuth of the hole was turned to a heading of N77°E. The fracture in GT-2 was kept inflated by hydraulic pressure ranging from 9.5 to 10.0 MPa (1420 to 1470 psi). When EE-1 intersected the fracture, it was expected that a decrease in the GT-2 pressure would occur. However, at a depth of 2954 m (9690 ft), a fluid loss of 1.6 m³/min (10 bbl/min) was experienced in EE-1, with no corresponding change in the pumping pressure in GT-2. Temperature logs run by GO-International the next day located a break in the casing at a depth of 82 m (270 ft). Remedial cementing operations were performed by Halliburton Oil Well Cementing Service on October 4 and 5. Four batches of 75 sacks each of neat cement and 3% calcium chloride were placed through open-ended drill pipe just above the break but failed to seal the leak. Two batches of 100 sacks each of cement containing Gilsonite and RFC additive were successful in sealing the break in the casings. The hole was washed to bottom and no further fluid loss occurred. Directional drilling was resumed with GT-2 again being pressurized.

On October 7, the stator blades in the Dyna-Drill assembly sheared off, having been softened by exposure to the heat in the hole. While a new directional drilling tool was being sent, drilling continued to a depth of 3011 m (9877 ft) with a conventional assembly. At that depth, a 1.1-m (3.6-ft) coring run was made with a 24.4-cm-o.d. by 15.2-cm-i.d. (9-5/8-in. by 6-in.) diamond core bit.

On October 10, additional acoustic-ranging measurements were conducted in EE-1 while pumping in GT-2. During these tests, a small flow of water was observed coming from EE-1 as GT-2 was pumped, marking the first evidence of a connection between the two holes.

Drilling ahead with the new Dyna-Drill assembly began on October 11 and was terminated the next day at a depth of 3065 m (10 053 ft). Over the following 11 days, a number of temperature logs, electric logs, pumping, and fracture experiments indicated the existence of a fracture connection between the two holes. On October 23, a string of casing with a minimum size of 19.4-cm diam

(7-5/8 in.) was set at a bottom depth of 2926 m (9600 ft) and cemented into place.

In cleaning out the casing, no cement was encountered between the float collar and the cement shoe. The hole was washed to 3050 m (10 007 ft) and circulated until clean. A cement bond log, run by Dresser-Atlas on October 27, indicated a 30 to 50% bond from 2926 to 2749 m (9600 to 9020 ft) and a 95 to 98% bond from 2749 to 2408 m (9020 to 7900 ft). The cementing was considered to be adequate and Signal Drilling Company rig was released at midnight. By November 4, the rig was completely disassembled and waiting for trucks to be moved away.

Figure 8 is a schematic cross-sectional view of EE-1.

Fig. 8.
Cross-sectional view of EE-1.

V. CASING

A. Conductor Casing

The conductor casing consisted of 3 m (10 ft) of 0.76-m- (30-in.-) diam corrugated metal pipe. The backfill concrete was furnished by a local ready-mix supplier, and consisted of 4.6 m^3 (6 yd^3) of 20.7-MPa (3000-psi) strength concrete containing 1.9-cm (3/4-in.) aggregate and 4% entrained air.

During the drilling of the volcanic rock, considerable leakage of drilling fluid occurred around the conductor casing and up the mouse and rat holes. This was attributed to the short length of conductor casing. A deeper string of conductor casing would probably have effected a better seal.

B. Surface Casing

The specifications provided for a string of surface casing to be set at an approximate depth of 181 m (595 ft). On June 2, after the hole was reamed to a depth of 178 m (584 ft), a string of 50.8-cm- (20-in.-) o.d. line pipe (Fig. 9) was set at a depth of 177 m (580 ft). A Baker cement shoe was installed at the bottom of the casing.

Fig. 9.
Setting surface casing in EE-1.

Cementing of the casing was performed by the Farmington, New Mexico branch of Byron Jackson, Inc. The cementing operation began at 2:30 p.m., June 2, by pumping 4.8 m³ (30 bbl) of water down the casing ahead of the cement, followed by 51.6 m³ (326 bbl) of cement slurry at a pressure of 3.4 MPa (500 psi). A wooden plug was run down the casing after the cement, which was displaced from the casing by pumping in 31.4 m³ (198 bbl) of water. Good circulation of the slurry was obtained at the surface; approximately 11 m (37 ft) of cement was encountered in the casing.

The total quantities of cement and admixtures are listed below:

*Cement, Ideal Class B	12.2 m ³	432 ft ³
*Pozzolan, Diamix F	10.0 m ³	352 ft ³
Bentonite (2%)	1199 kg	2643 lb
Calcium Chloride (2%)	1370 kg	3020 lb
Cello-Flake	23 kg	50 lb

C. Intermediate Casing

Prior to insertion of the intermediate casing, a 9-m³ pill (55 bbl) of 80-s viscosity** mud and 0.1 m³ (30 gal) of Baroid Torq-Trim was placed on bottom through the reaming assembly. During placement of the casing, two drums of Torq-Trim were mixed into the drilling mud to increase the lubricity of the borehole walls.

The bottom of the intermediate casing was set at a depth of 741 m (2431 ft). The casing was 34-cm-(13-3/8-in.-) o.d., 81.1 kg/m (54.5 lb/ft), Type K-55, Range 3. A Baker cement shoe was installed at the bottom of the casing with Baker float collars at 728 m (2390 ft) and 703 m (2307 ft). Cementing was planned to be done in three stages: at the bottom and through stage collars placed in the casing string at depths of 546.5 m (1783 ft) and 240.8 m (790 ft). Cement baskets were installed in the casing string just below each stage collar.

The cementing was done by Byron Jackson, Inc., and began at 3:30 p.m. on July 4, with 33.2 m³ (209 bbl) of cement slurry containing Pozzolan, silica flour, and Cello-Flake being injected under hydrostatic head. No water was pumped ahead of the cement, but 63.6 m³ (400 bbl) of gel-base mud had been injected just prior to the start of cementing.

*Measured in absolute volumes.

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

A rubber plug was run down the casing after the first-stage cement, pushed by displacement water. The usual pressure buildup was not observed when the plug hit bottom and the fluid depth in the holes after displacement was later measured to be 657 m (2157 ft). The plug apparently did not seat properly and the column of displacement water pushed all the cement out into the lost-circulation zone at the 716-m (2350-ft) depth.

Placement of the second-stage cement began at 10:30 p.m., with 35.8 m³ (225 bbls) of a similar slurry being injected. Cementing this stage produced results that were almost identical to the first stage, with no fluid remaining in the casing above the displacement plug. It was later reasoned that the lost-circulation zone took the cement slurry faster than it could be pumped in, leaving the casing empty when the displacement plugs were started down. The plugs and/or stage collars were probably not strong enough to withstand the force of the plugs hitting the empty stage collars with a full column of displacement water above them. As a result, they broke apart, letting the displacement water leak by and wash out the cement slurry below.

Cementing of the upper stage was postponed until circulation could be established. Three pills of approximately 95 m³ (600 bbl) each of mud containing 30 to 50% lost-circulation materials were pumped through the upper-stage collar in an effort to establish a bridge at the upper basket. On the third pill, full circulation was established, and the third stage cementing began at 1:15 a.m. on July 6, with 30.3 m³ (191 bbl) of cement slurry being injected. Circulation was maintained throughout the pumping sequence, but no cement came to the surface.

Cementing of the upper section of the casing was completed by injecting 5 m³ (175 sacks) of cement with 3% calcium chloride through a 2.54-cm- (1-in.-) diam pipe extending 43 m (140 ft) down the annulus between the inner and outer casings. Returns were obtained at the surface and the following morning hardened cement was found to be about 2.4 m (8 ft) down the annulus.

The total quantities of cement and admixtures for each stage are listed below:

First stage:

*Cement, Ideal Class B	5.0 m ³	176 ft ³
*Pozzolan, Diamix F	10.4 m ³	368 ft ³
Bentonite (2%)	314 kg	692 lb
Silica flour	5842 kg	12 880 lb

Cello-Flake	84 kg	184 lb
R-11 retarder (0.4%)	63 kg	138 lb
<u>Second stage:</u>		
*Cement, Ideal Class B	5.3 m ³	188 ft ³
*Pozzolan, Diamix F	11.2 m ³	394 ft ³
Bentonite (2%)	336 kg	740 lb
Silica flour	6255 kg	13 790 lb
Cello-Flake	45 kg	99 lb
R-11 retarder (0.2%)	34 kg	74 lb
<u>Third stage:</u>		
*Cement, Ideal Class B	4.5 m ³	160 ft ³
*Pozzolan, Diamix F	9.5 m ³	334 ft ³
Bentonite (2%)	285 kg	628 lb
Silica flour	5303 kg	11 690 lb
Cello-Flake	38 kg	84 lb

The bottom of the casing was later successfully cemented with 6.4 m³ (225 sks) of cement containing 3% calcium chloride and 283 kg (25 sks) of Cello-Flake through open-ended drill pipe.

D. Deep Casing

The deep string, consisting of 27.3-cm- (10-3/4-in.-) o.d., 75.9 kg/m (51 lb/ft), K-55, Range 3 casing was set at a depth of 1957 m (6420 ft) on August 13. To prevent the malfunction of the displacement plugs and stage collars as occurred in the intermediate casing cement operation, two float collars (a Baker below and a Halliburton above) were installed at the bottom of the casing and an aluminum plug landing baffle was inserted one casing joint up from the bottom. A Halliburton cast aluminum plug designed to withstand high landing pressures was also used.

Cementing was performed by Halliburton Oil Well Cementing Company, Farmington, New Mexico, on August 13. The operation began at 10:15 p.m. by pumping 1.6 m³ (10 bbl) of water into the casing, followed by 8.5 m³ (53.5 bbl) of cement slurry. The plug was displaced by 98 m³ (613 bbl) of water, and the hole shut in at 8.3 MPa (1200 psi). The volume of slurry and displacement water was calculated to cement the bottom 305 m (1000 ft) of the casing string.

*Measured in absolute volumes.

The quantities of cement and admixture are listed below:

*Cement, Ideal Class B.	2.7 m ³	95.6 ft ³
Silica flour	3411 kg	7520 lb
HR-12 retarder (0.3%)	25.4 kg	56 lb

E. Final Casing

Prior to placing the final casing, a taper mill and 6-point reamer assembly was run in the hole to ream the casing at the 64- to 81-m (210- to 265-ft) depth where a break had previously been cemented. On October 23, the final string of casing was set at a bottom depth of 2925 m (9599 ft). The string consisted of 304 m (999 ft) of 19.4-cm- (7-5/8-in.-) o.d., 39.3-kg/m (26.4-lb/ft) Grade N-80 casing on the bottom, with the remainder being 2627 m (8617 ft) of 21.9-cm- (8-5/8-in.-) o.d., 47.6-kg/m (32-lb/ft) Grade J-55. A Halliburton float shoe was installed on the bottom of the string with a Halliburton float collar and baffle plate inserted two casing joints up.

Halliburton Oil Well Cementing Company began cementing the following day pumping 1.6 m³ (10 bbl) of water down the casing, followed by 6.8 m³ (43 bbl) of cement slurry. A 21.9-cm- (8-5/8-in.-) diam wiper plug was run behind the cement, the rubber vanes being flexible enough to go down inside the 19.4-cm- (7-5/8-in.-) diam casing. The cement was displaced with 91 m³ (572 bbl) of water and the hole was shut in at 5.5 MPa (800 psi). The volume of the slurry and displacement water was calculated to cement the bottom 305 m (1000 ft) of casing.

The quantities of cement and admixture are listed below:

*Cement, Ideal Class B	2.4 m ³	83.6 ft ³
Silica flour	2612 kg	5758 lb
HR-12 retarder (2%)	149 kg	329 lb
CFR-2 friction reducer (1.6%)	119 kg	263 lb

During this cementing operation, water was pumped down GT-2 so that the hydraulic fractures would not become filled with cement slurry. It is probable that water flowing from GT-2 diluted the cement at the bottom of the casing, resulting in a poor cement bond.

VI. CEMENTING

Cementing operations to stabilize the hole, plug breaks in the casing, or seal fracture zones are described by dates of their occurrence.

*Measured in absolute volume.

A. June 25-26, 1975

1. Contractor. Byron-Jackson Company, Farmington, New Mexico.

2. Depth. Four successive cementing sequences, at 719 m (2359 ft), through open-ended drill pipe.

3. Total Slurry Volume. 25 m^3 (882 ft^3).

B. June 29, 1975

1. Contractor. Byron Jackson Company, Farmington, New Mexico.

2. Depth. Two plugs of 100 sks each placed at depths of 579 and 640 m (1900 and 2100 ft), through open-ended drill pipe.

3. Total Slurry Volume. 8.6 m^3 (304 ft^3).

C. August 26, 1976

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

2. Depth. 2099 m (6886 ft), through open-ended drill pipe; top of hardened cement encountered at 1975 m (6480 ft).

3. Total Slurry Volume. 6.6 m^3 (234 ft^3).

D. October 4-5, 1976

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

2. Depth. Four batches of 75 sks each, and two batches of 100 sks each at 82 m (270 ft), through open-ended drill pipe.

3. Total Slurry Volume. 21.3 m^3 (760 ft^3).

VII. DRILLING MEDIA

A. Mud

The services of Baroid began on May 27, 1975. A laboratory trailer was installed at the drill site and continuous supervision of the mud program was provided by two representatives who alternated tours. A local area supervisor kept himself informed of the operation and provided guidance when required.

The initial drilling fluid mix was a low-solids mud, consisting of a ratio of five sacks of Aquagel to one sack of Benex. This mix had a solids content of 3.5% by volume, a density of slightly less than 1 kg/liter (9 lb/gal), and a viscosity of 35 to 40 s. When slight lost-circulation problems were encountered, additions of Plug-git or cottonseed hulls were made to maintain 12 to 15% lost-circulation material. During the periods when large amounts of drilling

mud leaked up the rat hole and mouse hole, the lost-circulation material was increased to 25% and empty sacks were rammed down the holes.

While drilling in the upper Permian red beds, the viscosity was maintained at 50 to 60 s, and the weight at 1 kg/liter (9 lb/gal). The shale shaker and desilter were used continuously to keep the weight down. Additions of Driscose, Carbonox, and caustic soda were made each shift. As the depth increased, the viscosity was allowed to decrease to 35 to 40 s, with the mud weight increasing to 1.1 kg/liter (9.6 lb/gal).

On June 12, instructions were given to begin adding increased lost-circulation materials in preparation for the anticipated lost-circulation zone below the 580-m (1900-ft) depth. Circulation was lost at a depth of 581 m (1904 ft), but was restored with the addition of 30% lost-circulation material. Drilling resumed to a depth of 719 m (2359 ft) when circulation was again lost and the bit became stuck. Five pills of mud of 112 m³ each (700 bbls), containing 40% lost-circulation material (LCM) were pumped in the hole, but failed to restore circulation. While the pipe was being fished from the hole, returns were temporarily established with mud containing 70% LCM. Attempts to restore circulation were made by pumping numerous small batches of 24 m³ volume (150 bbl) of various mixtures of cottonseed hulls, Plug-git, Cello-Flake, Fibertex, and walnut shells with plain water, but without success.

After the casing was set and cemented, drilling continued with plain water and the mud program was terminated.

VIII. DRILL BIT PERFORMANCE

A. Volcanic Rock

Drilling through the volcanic tuff rock was accomplished in about 30 h with a 44.5-cm- (17.5-in.-) diam Security S88 sealed-bearing tricone insert bit. Reaming of the hole to a depth of 178 m (584 ft) was accomplished in about 60 h with a 66-cm- (26-in.-) diam Security hole-opening bit.

B. Sedimentary Rock

Drilling in the sedimentary section was done with full-bore 44.5-cm- (17.5-in.-) diam bits, instead of utilizing a pilot hole with a hole-opening bit. The expected lost-circulation problems in the limestone dictated a policy of drilling and setting casing as quickly as possible, making as few trips in and out of the hole as necessary.

Drill bits from two manufacturers were used; the drill footages and hours of use of each bit are recorded on the Drill Bit Record Charts in Appendix D. For the most part, a Hughes Tool Company OSC3A steel-toothed bit was used in the Permian beds with good results, penetrating at an average rate of 3.7 m/h (12 ft/h). A run of 46 m (133 ft) in 13-3/4 h was made with open jets and a subsequent run of 165 m (541 ft) in 43-3/4 h with 1.4-cm (18/32-in.) jets was made with the same bit. A Security S88 insert bit drilled in the Permian Formation at an average penetration rate of 4.8 m/h (15.6 ft/h), but balled up with clay and was pulled after penetrating 37 m (121 ft).

Penetration rates in the Madera Limestone were considerably less than in the Permian sediments and insert bits were used almost exclusively. The longest run was 137 m (450 ft) in 104 h with a Hughes Tool Company J44 bit.

A stiff bottom-hole assembly was used in drilling the sedimentary beds to minimize hole drift. The assembly consisted of near-bit three-point reamers, a 3-m (10-ft) drill collar, a steel stabilizer with replaceable wear pads, a 9-m (30-ft) drill collar, and a rubber stabilizer. In the lower portion of the sedimentary beds, a 4.1-m (13.3-ft) shock sub was inserted between the bit and the near-bit reamers.

C. Granitic Rocks

Drilling in the 31.1-cm- (12-1/4-in.-) diam section of the hole was done with both Smith Q9J and Security H100 insert rock bits. A comparison of the performance of these two bits is shown in Table I. A comparison of the different types of wear encountered in each bit type is shown in Fig. 10. Weight on the bit ranged from 27.2 to 31.7 Mg (60 000 to 70 000 lb) with a rotational speed of 40 to 50 rpm.

Drilling the 24.5-cm- (9-7/8-in.-) diam section of the hole below 1957 m (6420 ft) was done almost exclusively with Security H10 JP bits.

The maximum total deviation of EE-1 above 1957 m (6420 ft) was 7-3/4 degrees; after directional drilling was begun, at 2099 m (6886 ft), the deviation varied from 8-1/4 to 3-3/4 degrees. The usual bit rotational speed for standard drilling was 40 rpm; for directional drilling, the bit speed was 250 rpm at 3.2 Mg (7000 lbs) load. While this increased rotational speed greatly improved the penetration rate, the bit life was drastically reduced.

Average penetration rates in the crystalline rocks ranged from a low value of 0.9 m/h (2.8 ft/h) for standard drilling to a maximum of 11.6 m/h (38 ft/h) for a 2-h period of directional drilling at a depth of 2976.7 m (9766 ft). The

TABLE I

EE-1 31.1-CM-DIAMETER ROCK BIT PERFORMANCE

Manufacturer and Type	Depth Drilled		Time Elapsed (h)	Penetration Rate				Depth Out	
	(m)	(ft)		(m/ h)	(ft/ h)	(m/ day)	(ft/ day)	(m)	(ft)
Smith Q9J	108	(354)	71	1.5	(5.0)	34.4	(113)	848.9	(2785)
Smith Q9J	103	(338)	57	1.8	(5.9)	39.0	(128)	951.9	(3123)
Security H-100	198	(650)	107-1/2	1.8	(6.0)	41.4	(136)	1149.1	(3770)
Smith Q9J	119	(391)	73-3/4	1.6	(5.3)	35.1	(115)	1269.2	(4164)
Security H-100	229	(752)	96-3/4	2.4	(7.8)	52.1	(171)	1498.4	(4916)
Smith Q9J	107	(350)	68	1.5	(5.1)	33.2	(109)	1605.1	(5266)
Security H-100	250	(821)	107	2.3	(7.7)	51.2	(168)	1855.3	(6087)
Smith bit, <u>Average</u>	109	(358)	67	1.6	(5.3)	35.4	(116)		
Security bit, <u>Average</u>	226	(741)	104	2.2	(7.2)	48.2	(158)

Fig. 10.

Comparison of Smith Q9J bit and Security H-100 bit after use in EE-1.

maximum drilled interval for a 31.1-cm- (12-1/4-in.-) diam bit was 250.2 m (821 ft) in 106 h at a depth of 1855.3 m (6087 ft). The maximum standard drilling interval for a 24.5-cm- (9-7/8-in.-) diam bit was 117.0 m (384 ft) in 42 h. In contrast, the longest bit run during directional drilling was 34.4 m (113 ft) in 5 h.

Because of the Smith bit's intended use and carbide availability, it was fitted with somewhat softer tungsten carbide inserts than the Security bit. The Security H-100 bit was a more advanced, oil-field-type rock bit, fitted with prelubricated and sealed roller bearings, and intended for mud or water circulation only.

These two types of bits were used exclusively for drilling the 31.1-cm-diam hole interval in EE-1 for two reasons: (1) these were the only types of 31.1-cm-diam hard-rock bits available, and (2) there was a desire to compare the performance of two manufacturers' equivalent hard-rock bits.

As shown in Table I, the H-100 bits outperformed the Q9J bits in average rate of penetration and average bit life. The H-100 bits tended to drill 35% faster and lasted almost twice as long as the Q9J mining bits. The H-100 average bit performance of almost 49 m/day (160 ft/day), for a 31.1-cm hole in granite, is outstanding compared with typical oil-field drilling performance in hard rocks. Its longer life was due to the sealed bearings and the harder carbide inserts. As shown in Fig. 10, the inserts of the Q9J bit wore smooth and the bit just stopped "digging" sooner than the H-100 bit. The few broken carbide inserts in the H-100 bit (because of its harder, more brittle grade of tungsten carbide) did not slow the bit appreciably, and the sealed bearings increased its life for many more hours.

Drilling the 24.5-cm- (9-7/8-in.-) diam section of the hole below 1957 m (6420 ft) was done almost exclusively with Security H10 JP bits.

IX. CORING

Two coring runs were made in EE-1; a summary of the runs is included as Table II. The first run was made with a modification of a bit used by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). These bits, measuring 24.4-cm o.d. by 6.2-cm i.d. (9-5/8-in. o.d. by 2-7/16-in. i.d.) were manufactured and modified by the Smith Tool Company. The second coring run was made with a 24.4-cm-o.d. by 15.2-cm-i.d. (9-5/8-in.-o.d. by 6-in.-i.d.) diamond bit manufactured by American Coldset Corporation.

TABLE II
SUMMARY OF CORING RUNS, EE-1

Core Run	Core Interval Depth	Recovery	Core Bit	Rock Type ^c
1	2095 - 2099 m (6874 - 6886 ft)	25%	J ^a	Leucocratic monzogranite gneiss
2	3011 - 3012 m (9877 - 9881 ft)	17%	ACC ^b	Leucocratic granodiorite

^aJOIDES-type bit.

^bAmerican Coldset Corporation bit.

^cRock types determined from petrographic examination of thin sections.

For a detailed description of the geologic cores in EE-1, see Ref. 21.

X. DIRECTIONAL DRILLING

The Dyna-Drill has many advantages not offered by other equipment or methods. Because it incorporates its own downhole motor, Dyna-Drill does not require the drill pipe to be rotated as in conventional rotary drilling. The positive displacement motor is powered by the drilling fluid, air, or gas used in normal drilling operations.

The power-generating source of the Dyna-Drill is a multi-stage Moyno-pump used as a motor. This specially designed motor consists of a rotor and a stator, a rubber-like element molded with a spiral passageway having an oblate cross section.

Rotation occurs when drilling fluid is forced under pressure into the cavities between rotor and stator. The upper end of the rotor is unattached and exposed to the flow of drilling fluid. The lower end of the rotor is attached to a connecting rod, which in turn is connected to the drive shaft. The connecting rod converts eccentric rotation of the rotor to concentric rotation of the drive shaft. The lower end of the drive shaft is designed to accommodate the drill bit.

With the Dyna-Drill, programmed directional drilling is achieved by including a bent section in the nonrotating drilling assembly near the drill bit. As the drill and nonrotating bent assembly advance, a continuing gradual arc of

hole curvature is created because the Dyna-Drill carries its own bending force along as it drills.²²

Directional drilling was begun in EE-1 at 2099 m (6886 ft) and marked the start of Phase II. Because the azimuthal orientation of the fracture extending from GT-2 was uncertain at this time, the decision was made to maximize the probability of intersecting it by directing EE-1 toward a point about 60 m (200 ft) directly below the bottom of GT-2--through which, so long as it extends downward at least 60 m, any vertical fracture from GT-2 must pass. The hole was turned through a slow spiral from an azimuthal direction of about N78°W to about S23°E and back to S20°W at 2918 m (9575 ft), and was steepened to a deviation of 3-3/4 degrees from the vertical--so that it could be flattened again as the target was approached. It is thought that this was the first time that directional drilling had been attempted in hot granitic rock, and it was very successful. (See Sec. VIII for bit performance during directional drilling.)

XI. LOGGING

Diagnostic logging operations were performed in the hole by three commercial logging companies and by personnel of the Los Alamos Scientific Laboratory.

A total of six diagnostic logging operations was performed commercially. Summaries of these operations are shown in Figs. 11-14, which designate the depths at which each type of log was run, the dates, and the company that performed the work. In addition to these diagnostic logs, commercial logging companies also performed temperature surveys, induced-electric-potential and self-potential logs in the hole, in conjunction with tests and experiments performed by LASL personnel.

The entire hole was logged to determine lithology, hole condition, and the integrity of the casing cement. Logs to determine permeability, rock competency and fracture zones were also run in the Precambrian section of the hole.

Logging operations in EE-1 were generally more efficient than in GT-2. It was learned, for instance, that the dipmeter and neutron logs were of doubtful value, and these logs were not run in EE-1.

A fairly good correlation of the lithology between the two holes was established below the 1830-m (6000-ft) depth using both cuttings and data from the spectral-gamma logs. Intervals of leucocratic monzogranite encountered

Fig. 11.
Diagnostic logging services performed
in EE-1 during June 1975.

Fig. 12.
Diagnostic logging services performed
in EE-1 on August 11, 1975.

Fig. 13.
Diagnostic logging services performed in EE-1 on August 8-12, and August 22, 1975.

Fig. 14.

Diagnostic logging services performed in EE-1 during September and October 1975.

in GT-2 roughly corresponded to peaks on the spectral-gamma logs. Distinctly dark-colored cuttings from the biotite-rich intervals in both holes correlated with changes on the spectral-gamma log.

A description of the logging operations performed in conjunction with the experimental testing will be included in the following section.

XII. EXPERIMENTS

A series of hydraulic fracturing, impression packer, acoustic-ranging, fracture-mapping, and logging experiments was conducted in EE-1 and GT-2 at various depths. These experiments will be described briefly in chronological order. Detailed descriptions and the interpretation of the experiments have been included in other reports.²²

After the deep casing had been set to the 1957-m (6420-ft) depth, the hole was drilled an additional 142 m (466 ft) to provide a fresh, open-hole section for the first group of experiments.

A. August 21 to August 31, 1975

1. August 21. Background self-potential electric logs were run in the open-hole section by Schlumberger Well Services to provide a record of the hole condition before testing began.

2. August 22. The LASL seismometer package (with its amplifiers in ice-filled dewars) was set at 2012 m (6600 ft) in GT-2 and a series of five 3-m- (9-ft-) long Primacord shots was detonated by GO-International Inc. at the 744- to 762-m (2440- to 2500-ft) depth in Hole GT-1 (located in Barley Canyon approximately 2.4 km to the north¹¹). No seismic signals were observed in GT-2.

GO-International then moved to EE-1 and detonated a series of 30.5-cm- (12-in.-) long Primacord shots at depths of 2073 m, 2012 m, 1951 m, and 1890 m (6800 ft, 6600 ft, 6400 ft, 6200 ft). The LASL seismometer package was positioned in GT-2 to match the depths of the detonations in EE-1. Seismic signals were observed from all the detonations in this series.

3. August 23. The LASL seismometer package was set at 2007 m (6585 ft) in GT-2, and EE-1 was pressurized with the Western Company pump for a fracture experiment. The pumping rate was gradually raised from 0.17 m³/min to 0.94 m³/min (1 bbl/min to 5-1/2 bbl/min), with a maximum pressure of 8.3 MPa (1200 psi) being achieved. There was no evidence of fracture initiation in EE-1; but when the hole was vented considerable water flowed back, which indicated

the possibility of a preexisting fracture zone. An attempt was made to run a Schlumberger Well Services Company spinner log in the pumped zone, but the tool did not function properly and no logs were obtained. No signals were observed in GT-2 from this pumping experiment in EE-1.

4. August 25. A Lynes inflatable packer was set in EE-1 at the 1975-m (6480-ft) depth, 18.3 m (60 ft) below the bottom of the casing. The LASL seismic package was set in GT-2 at 1967 m (6455 ft). Inflation of the packer was accomplished with an initial pressure of 10.3 MPa (1500 psi) by the Haskell pump in the LASL trailer. The inflation pressure was gradually increased to keep it about 1.4 MPa (200 psi) above the hole-pumping pressure. The LASL Kobe pump was used to pressurize the interval of open hole between the packer and the bottom of the casing. Maximum flow into the interval was $0.03 \text{ m}^3/\text{min}$ (9.1 gpm) with approximately 3 m^3 (800 gal) being injected. Definite fracture initiation (breakdown) occurred at a pressure of 13.1 MPa (1900 psi). A self-potential electric log later indicated the fracture had been formed between the depths of 1962 and 1967 m (6437 and 6454 ft).

The system was then vented, the Lynes packer was allowed to deflate, and pumping was resumed to pressurize the entire hole below the casing. A maximum pressure of 2.1 MPa (300 psi) was achieved with the results being much the same as the pumping experiment on August 23. The packer was then moved down 73 m (240 ft) and reset. The system was again pressurized to a maximum of 9.5 MPa (1375 psi), with about 1.9 m^3 (500 gal) being injected. No seismic signals were observed in GT-2 from any of the pumping sequences in EE-1.

This series of tests definitely established the presence of a naturally fractured zone in the bottom of the hole, which required cementing before further testing could progress.

5. August 26. Halliburton Oil Well Cementing Company was called from Farmington, New Mexico, to cement the fractured zone in the bottom of EE-1. (See Sec. VI, C.) Preparations were made to set a Lynes impression packer across the fractured zone.

6. August 27. A 1.5-m- (5-ft-) long Lynes inflatable impression packer was centered at 1964 m (6443 ft) and inflated with the LASL Haskell pump. The interval between the packer and the top of the cement at 1975 m (6480 ft) was pressurized with the Kobe pump at a flow rate of $0.03 \text{ m}^3/\text{min}$ (9 gpm). The previously made fracture opened up at a pressure of 12.8 MPa (1850 psi); after

5 min, the pressure decreased to 11.9 MPa (1730 psi), then climbed to 13.4 MPa (1950 psi) after an hour of continued pumping.

The Lynes impression packer was set at a pressure of 17.2 MPa (2500 psi) for a period of 45 min. During this time, part of the fracture was evidently sealed off as the flow rate through the Kobe pump decreased substantially. When the packer was pulled from the hole, it was found that the soft rubber sleeve had remained in the hole and no impressions were obtained. Preparations were begun by Schlumberger Well Services Company to run self-potential logs in the hole, in conjunction with a series of detonation experiments.

7. August 28. Before the detonation experiments, a series of self-potential electric logs was run in the open-hole section of EE-1 to examine the fracture in the following conditions:

- Background with fracture collapsed, prior to pumping.
- Fracture pressurized to 14.1 MPa (2045 psi), open and being pumped.
- During shut in, with pressure fairly constant.
- During vent stage.
- Background with fracture collapsed after pressurization.

After the seismometer package was set at the 1966-m (6450-ft) depth in GT-2, a series of Primacord shots was detonated in EE-1 by GO-International to map the extent of the hydraulic fracture. It was intended to make five detonations at each depth setting in EE-1, but due either to the high temperature or to misfires, not all the shots detonated as planned. Detonations were made with the fracture in the following conditions:

<u>Condition of Fracture</u>	<u>Depth of Shots</u>
Fracture open; pumped 1 hr at 0.03 m ³ /min (9 gpm), 12.6 to 13.1 MPa (1830 to 1900 psi).	1972 and 1964 m (6470 and 6443 ft)
Fracture closed; system vented.	1972 and 1964 m (6470 and 6443 ft)
Fracture open; pumped 30 min at 0.03 m ³ /min (9 gpm), 12.4 MPa (1800 psi).	1957 m (6420 ft)
Fracture closed; system vented.	1957 m (6420 ft)

During the series at 1957 m (6420 ft), the condition of the geophones in the seismic packages was deteriorating due to the heat, and the No. 2 horizontal geophone became completely inoperable.

8. August 29. The LASL electrical current probe was set in the hydraulic fracture zone in EE-1 at about 1966-m (6450-ft) depth. With EE-1 unpressurized, Schlumberger ran a background self-potential log in GT-2; the effects of the induced change in the electrical potential created in EE-1 were definitely established. It was planned to run similar logs in GT-2 during and after a pumping sequence of the fracture in EE-1, but a malfunction of the Schlumberger logging tool prevented this experiment from being concluded, and the logging operations were terminated.

9. August 30. An oriented Lynes impression packer assembly was run down the hole and set in the hydraulic fracture zone at a pressure of 15.9 MPa (2300 psi) for 4 h, while the fracture was being pumped at 13.8 MPa (2000 psi). The packer assembly consisted of two 1.5-m (5-ft) elements, spaced 1.8 m (6 ft) apart with the elements centered at depths of 1962 and 1966 m (6438 and 6449 ft).

10. August 31. The packer assembly was pulled from the hole. Definite impressions of the hydraulic fracture were obtained which indicated the fracture was oriented in a NW-SE direction. Drilling began on the cement plug at a depth of 1975 m (6480 ft).

B. September 20, 1975

A series of seismic ranging experiments was conducted between the two holes to determine their relative positions. The new geophone package with brass-tipped locking arm (Fig. 15) was centered at the 2774-m (9100-ft) depth in EE-1. Detonator caps were exploded in GT-2 at depths of 2749, 2764, and 2779 m (9018, 9068, and 9118 ft) by GO-International. (A depth of 2764 m [9068 ft] in GT-2 was equivalent to 2774 m [9100 ft] in EE-1.) On the basis of the seismic signals received in EE-1, the distance between the two holes was calculated to be approximately 15 m (50 ft). The position of one hole relative to the other appeared to be calculable to within one degree. Drilling resumed in EE-1 and continued until September 24 to a depth of 2918 m (9575 ft).

C. September 25 to October 1, 1975

1. September 24. Electric self-potential logging operations were begun in EE-1 by Dresser-Atlas Petroleum Services in an attempt to determine the extent of the fracture zone at the bottom of GT-2.

2. September 25. The LASL electrical probe was run down GT-2 while SP logs were being run in EE-1 by Dresser-Atlas. The experiment was conducted without pumping in GT-2 to determine background values. At the end of the day

Fig. 15.
Schematic view of geophone package.

when the electrical probe was pulled, it was found that part of the probe had broken off and had remained in the hole. As a result, the logging cable had filled with water and had become inoperable.

3. September 26. While the electric logging equipment was being repaired, a seismic-ranging experiment was conducted between GT-2 and EE-1.

The geophone package was placed on bottom in EE-1 while pumping was conducted in GT-2. Approximately 13.6 m^3 (3600 gal) of water were injected over a 7-h period at a maximum pressure of 11.0 MPa (1600 psi). However, no discernible seismic signals were detected.

Three GO-International detonators were made up on the Dresser-Atlas cable, with a LASL firing mechanism and geophone trigger assembly. The LASL geophone was set at 2915 m (9565 ft) in EE-1, but trouble with the extendable arm prevented it from being locked into place. The detonators were lowered in GT-2, one was fired at 2905 m (9531 ft) and the second at 2920 m (9581 ft). The third shot, meant to be fired at 2890 m (9481 ft), did not go off. Good signals were detected in EE-1, in spite of the fact that the geophone package was not

locked to the side of the hole. Preliminary calculations indicated that the holes were approximately 8 m (26 ft) apart at the 2905-m (9531-ft) depth; however, the Eastman camera malfunctioned and no indication of direction could be obtained.

4. September 27, 28. No experiments performed; repaired and modified equipment.

5. September 29. The LASL electrode probe was run down GT-2 on the GO-International cable, while Dresser-Atlas was running SP logs in EE-1. In spite of continued problems with the SP tool, satisfactory background value tests were conducted.

At 4:00 p.m., the fracture at the bottom of GT-2 was inflated using the Western pump. A total of 11.4 m^3 (3000 gal) was injected at a maximum pumping rate of $2.0 \text{ m}^3/\text{min}$ (3.7 bbl/min) and a maximum pressure of 15.2 MPa (2200 psi). The Western pump was shut off, and pumping continued with the Kobe pump at a rate of $0.03 \text{ m}^3/\text{min}$ (9 gpm). A series of SP logs was run in EE-1 while the fracture was inflated. After 1.5 h of pumping with the Kobe, the experiment was terminated and GT-2 was vented.

6. September 30. An additional ranging experiment was conducted between GT-2 and EE-1, similar to the experiment performed on September 26. Three GO-International detonators (this time encapsulated in RTV) were made up on the Dresser-Atlas cable with a LASL firing mechanism and geophone trigger assembly, and lowered into GT-2. The bottom of the LASL geophone package was set on the bottom of EE-1, as continuing trouble with electrical connections through the cable head prevented the locking arm from being extended. The actual depth of the geophones was 2913 m (9558 ft); and the first detonator was fired in GT-2 at a depth of 2906 m (9535 ft), which corresponded to the depth of the geophones in EE-1. The second shot at a depth of 2914 m (9562 ft) did not fire, but the third shot at 2899 m (9512 ft) was fired satisfactorily. At about the same time a dynamite charge of one-third case was fired in a hole about 2.4 km (1-1/2 mi) to the southeast on Cebollita Mesa. Only one horizontal geophone was working, but good signals were received from the detonators and the dynamite shot.

Both the firing package and the geophone package were pulled from their respective holes, and the geophone Dewars were reiced. The electric probe on the GO-International cable was run down GT-2 and the geophone package reinserted in EE-1 to the bottom. Another dynamite shot of two-thirds case was fired in

a hole 2.4 km (1-1/2 mi) to the south, with signals being received in EE-1. The Eastman camera worked satisfactorily on both downhole seismic experiments and provided orientation of the geophone package. (The dynamite shots were set off to provide backup orientation if the Eastman camera did not work.) As a result of these experiments, the position of EE-1 at a depth of 2913 m (9558 ft) was determined to be 8 m (26 ft) away from GT-2 in a nearly due west direction (later determined to be the wrong direction).

At about 8:00 p.m., pumping began in GT-2 with the Western pump truck. In 1.5 h, approximately 45.5 m^3 (12 000 gal) were injected at a maximum pumping rate of $0.7 \text{ m}^3/\text{min}$ (4 bbl/min) and pressure of 15.5 MPa (2250 psi). The pumping rate was varied from zero flow through stepped increments while seismic data were recorded. The Western pump was shut in at 9:35 p.m., pumping began with the Kobe pump and the geophone package was withdrawn from EE-1.

At 11:00 p.m., the SP logging tool was run down EE-1 by Dresser-Atlas with GT-2 being continually pumped with the Kobe pump. Logging continued until 2:00 a.m., GT-2 was vented and the electrode withdrawn. The hole was repressurized by the Western pump truck at 4:00 a.m., with the continued pumping being done with the Kobe pump.

D. October 10 to October 21, 1975

1. October 10. Several experiments were run in EE-1 while the Western pump was injecting water in GT-2. Approximately 44.3 m^3 (11 700 gal) were pumped in at a rate of $0.7 \text{ m}^3/\text{min}$ (4 bbl/min) and a maximum pressure of 14.8 MPa (2150 psi). While pumping, the geophone package was lowered in EE-1 and positioned at depths of 2807, 2868, 2943, and 3004 m (9211, 9409, 9656, and 9856 ft) to determine the top and the bottom of the fracture in GT-2. Then the LASL SP tool was run down EE-1 and the same anomaly was noted at about 2896 m (9500 ft) as was seen in previous Dresser-Atlas logs. Also, another anomaly was seen at about 3004 m (9856 ft), which was duplicated in two more logging runs.

The first evidence of a connection between the two holes was noted when EE-1 continued flowing as GT-2 was pumped.

2. October 11, 12. Drilled to 3065 m (10 053 ft), circulated hole; GT-2 kept pressurized to 10.1 MPa (1470 psi).

3. October 13. A background SP log was run in EE-1 with pumping shut off in GT-2, and the pressure decayed to 1000 psi. The anomaly at 3004 m (9856 ft) was not seen on this test. A background temperature log was then

run in EE-1, which showed a temperature rise of 4 to 5°C at about 2896 m (9500 ft). The Western pump then injected 28.1 m³ (7400 gal) in GT-2, during which time another temperature log was run. Very little change in the temperature profile was noted on this second run. Another SP log was run in EE-1 while 17.1 m³ (4500 gal) were injected in GT-2. The anomaly at 3004 m (9856 ft) was not noted in the second logging run.

4. October 14. A Lynes inflatable packer was set in EE-1 at a depth of 2926 m (9600 ft). GT-2 was inflated to 14.5 MPa (2100 psi) with the Western pump, and then pumped continuously with the Kobe pump. The pressure in GT-2 dropped rapidly to 12.4 MPa (1800 psi) when the Western pump was removed. The Western pump was hooked up to EE-1, with water being injected at gradually increasing rates up to 0.4 m³/min (2.1 bbl/min) at a pressure of 16.6 MPa (2400 psi). As soon as EE-1 was pumped, the rate of pressure drop in GT-2 decreased and the pressure finally leveled off at 10.3 MPa (1500 psi). After 14.0 m³ (3700 gal) had been injected in EE-1, the packer failed and EE-1 was vented, whereupon the pressure in GT-2 gradually decreased. With continuous pumping in GT-2 with the Kobe pump at a rate of 0.03 m³/min (9 gpm), the pressure stabilized at 8.2 MPa (1190 psi). When the packer was pulled, a flow of approximately 0.013 m³/min (4 gpm) was measured coming from EE-1.

A hydraulic fracture was created in EE-1 below 2926 m (9600 ft) by this pumping operation and a definite connection was established as evidenced by the pressure response in GT-2.

5. October 15. Pumping in GT-2 continued through the day until 4:00 p.m. With 0.024 m³/min (6.2 gpm) being injected in GT-2 at a pressure of 8.2 MPa (1190 psi), the flow from EE-1 was about 0.019 m³/min (5 gpm). A temperature log and an SP log in EE-1 showed a very sharp anomaly at the 2941-m (9650-ft) depth.

6. October 16. A Lynes inflatable packer was run down EE-1 to be set at about 2987 m (9800 ft) in an attempt to create a hydraulic fracture at a lower depth. Trouble was experienced in getting it past the 2926-m (9600-ft) depth; a valve in the packer malfunctioned, making it impossible to seat. When the packer was pulled from the hole it was badly torn. A bit was then run in, and the hole reamed from 2917 to 3023 m (9570 to 9918 ft), then circulated for 3 h.

7. October 17. A second Lynes packer was run in the hole to 2944 m (9822 ft). Attempts to inflate the packer were unsuccessful, and when the drill pipe was pulled, the entire packer assembly was left in the hole.

8. October 18, 19. Another packer was run in on October 18, but it could not be lowered below 2828 m (9278 ft). When it was pulled, the bottom third of that assembly remained in the hole. A bit was installed on the drill pipe and both packers were pushed down the hole to a depth of 3055 m (10 022 ft).

9. October 20. A Lynes packer was successfully set at 2984 m (9791 ft). The Western pump truck was used to pump through the packer; at a pressure of 22.8 MPa (3300 psi) the annulus level began to rise indicating a leak around the packer. There was apparently no fracture of the rock at that pressure. The packer by-pass valve was opened with the wire-line and the hole was circulated. Temperature logs were run later in the day with LASL instruments.

10. October 21. Another Lynes packer was run in, but it tried to seat itself at about 244 m (800 ft) and was pulled. The hole was then reamed and circulated to 3055 m (10 022 ft); a taper mill and 6-point reamer were used to mill out the casing at the 64- to 81-m (210- to 265-ft) depth in preparation for setting the 19.4-cm- (7-5/8-in.-) diam casing. Pumping tests from GT-2 to EE-1 were later conducted with the Western pump while SP and induced-potential logs were run in both holes with LASL equipment. The measured flow from EE-1 was about $0.019 \text{ m}^3/\text{min}$ (5 gal/min).

Testing during the drilling phase in EE-1 was completed on this date, the final casing was set on October 23 and the drilling rig was released on October 27.

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 South-western Petroleum Short Course, Texas Tech University, Lubbock, Texas, April 26-27, 1973, pp. 249-255.
3. B. C. Renich, "Geology and Ground-Water Resources of Western Sandoval County, New Mexico," U. S. Geological Survey 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," U. S. Geological Survey 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," U. S. Geological Survey 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," New Mexico 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," U. S. Geological Survey Bull. 1274-P (1969).
8. R. L. Smith, R. A. Bailey, and C. S. Ross, "Geological Map of the Jemez Mountains, New Mexico," U. S. Geological Survey 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 (August 1973).
11. W. D. Purtymun, "Geology of the Jemez Plateau West of the Valles Caldera," Los Alamos Scientific Laboratory report LA-5124-MS (February 1973).
12. F. G. West, "Geohydrology of the Jemez Plateau," paper presented at the Annual Fall Meeting, 1973 American Geophys. Union, San Francisco, CA, Dec. 10, 1973.
13. 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).
14. 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 LA-5780-MS (Nov. 1974).
15. R. A. Pettitt, "Planning, Drilling, and Logging of Geothermal Test Hole GT-2, Phase I," Los Alamos Scientific Laboratory report LA-5819-PR (Jan. 1975).
16. R. A. Pettitt, "Testing, Drilling, and Logging of Geothermal Test Hole GT-2, Phase II," Los Alamos Scientific Laboratory report LA-5897-PR (March 1975).
17. F. G. West, P. R. Kintzinger, and W. D. Purtymun, "Hydrologic Testing of Geothermal Test Hole No. 2," Los Alamos Scientific Laboratory report LA-6017-MS (July 1975).

18. J. N. Albright, "Temperature Measurements in the Precambrian Section of Geothermal Test Hole No. 2," Los Alamos Scientific Laboratory report LA-6022-MS (July 1975).
19. R. A. Pettitt, "Testing, Drilling and Logging of Geothermal Test Hole GT-2, Phase III," Los Alamos Scientific Laboratory report LA-5965-PR (June 1975).
20. F. G. West, P. R. Kintzinger, and A. W. Laughlin, "Geophysical Logging in Los Alamos Scientific Laboratory Geothermal Test Hole No. 2," Los Alamos Scientific Laboratory, unpublished data, 1975.
21. A. W. Laughlin and A. C. Eddy, "Petrography and Geochemistry of Precambrian Rocks from GT-2 and EE-1," Los Alamos Scientific Laboratory report to be published.
22. A. G. Blair, J. W. Tester, J. J. Mortensen, Comps., "LASL Hot Dry Rock Geothermal Project; July 1, 1975 - June 30, 1976," Los Alamos Scientific Laboratory report LA-6525-PR (October 1976).

APPENDIX A

SPECIFICATIONS FOR ENERGY EXPERIMENT HOLE NO. 1

January 24, 1975

Specification No. LAB-SP-3745

Part A-I

SPECIAL CONDITIONS

SC-01. STATEMENT OF WORK

A. Location. The drilling site for EE-1 is located in the northeast quadrant of Section 13, T19N, R2E, Sandoval County, New Mexico. The site, at an elevation of 8700 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, 35 road miles west of Los Alamos and 15 road miles north of Jemez Springs. A 200-yard-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. Prepare a drilling location as shown in the attached grading plan (not included in this report) to include a 250 000-gal reserve pit.

2. Using a large earth auger, drill a 48-in.-diam hole to a depth of 10 ft; set in concrete to ground level, a 10-ft length of 30-in.-diam corrugated metal pipe to act as a conductor pipe for the subsequent drilling of the 26-in.-diam surface hole.

3. Drill a 26-in. surface hole to 600 $\pm$ ft. Circulating fluid: mud.

4. Run and set 20-in. casing to 595 $\pm$ ft; cement as directed.

5. Drill a 17-1/2-in. hole to at least 2200 ft; and to 2600 ft if the anticipated severe lost-circulation problems below 1900 ft can be adequately overcome. Circulation fluid: mud to 1900 ft; mud, aerated mud, or stiff foam below 1900 ft. Run logs and surveys as directed.

6. Run and set 13-3/8-in. casing 5 ft above the bottom of the 17-1/2-in. hole; cement as directed.

7. Drill a 12-1/4-in. hole to a depth of approximately 5400 ft with several 24-h drilling delays for bottomhole temperature measurements. Circulating fluid: water or water in combination with intermittent volumes of mud. At the terminal depth, run logs and surveys as directed.

8. Run and set 10-3/4-in. casing to 5400 $\pm$ ft; cement as directed.

9. Drill a 9-5/8-in. hole to a depth of between 12 000 and 13 000 ft, with intermittent coring mainly below the terminal depth for GT-2 (9620 ft). Conduct bottomhole temperature measurements as directed by the University.* Circulating fluid: water.

10. Run diagnostic logs and surveys; in situ hydrology and rock mechanics experiments, as directed by the University.

11. Conduct large-scale hydraulic fracturing operations and related experiments as directed by the University.

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

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 A-V.

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

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 provisions of SC-05; Paragraph 6, Special Items and Services, are listed in Part A-VI.

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 late March 1975.

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 and a supervisor 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.

Note: In addition to the Contractor's Supervisor (tool pusher), the University will provide an experienced and well-qualified Drilling Superintendent to act as the University's Drill-Site Supervisor. This individual is intended to provide improved Contractor supervision and better coordination between on-site University activities and personnel, and the Contractor.

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 drilling location preparation (including the reserve pit and conductor hole), 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-VIII). Mobilization shall be considered complete when the drilling location is prepared, the conductor pipe set, all equipment is rigged up, operational, and the Contractor is ready to start drilling the surface (26-in.-diam) hole.

2. Standard Hourly Rate Operations. All operations under this category (to include normal making-up and rigging of tools) 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 and hole opening
- (4) Logging
- (5) Testing
- (6) Running casing
- (7) Cementing
- (8) Waiting on cement
- (9) Waiting for orders
- (10) Hydrology
- (11) Hydraulic fracturing
- (12) Directional drilling
- (13) Bottomhole temperature measurements

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 A-VIII).

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

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

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. The University, at its option, may have these operations performed under the hourly rate schedule listed below (Item 5).

5. Demobilization Hourly Rate Operations. All operations under this category, as operationally described under Item 4 above (Demobilization), shall be performed by the Contractor with a full complement of operating personnel. This rate schedule, at the option of the University, will replace the separate fixed bid for Demobilization (Item 4) submitted by the Contractor. All additional equipment and personnel required for the Demobilization operation, not otherwise specified in Part A-V, (Minimum Equipment and Service Requirements to be Furnished by the Contractor), will be reimbursed by the University under Item 6, below (Special Items and Services).

6. 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 3 of the University of California Request for Quotation.

c. Payment for these special tools, materials, and services will be made under Item No. 6 of the Unit Price Schedule (Part A-VIII) 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 IADC API Report Form acceptable to the University. The Unit Price Schedule (Part A-VIII) quantities (Items 1 through 5) for payment purposes will be taken from the copy of the IADC Daily Drilling Report available 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, elapsed hours, rotating hours, 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.

D. Necessary University and ERDA Safety Forms

(Not included in this report.)

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

A. Contractor's Surface Equipment. The 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 12 000 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 A-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 A-III). If hole problems and/or circulating problems are encountered, the University may direct the use of air, stiff foam, direct circulation using aerated water and/or drilling mud.
- D. Tests of blowout preventers.
 - 1. The drill collar or pipe rams shall be closed on the drill pipe once each 24 h or as requested, while drilling operations are in progress.
 - 2. The blind rams shall be closed on each trip for a new bit.
 - 3. Periodic pressure tests of the entire BOP stack, as requested by the University, shall be made after the shoe has been drilled out on the 10-3/4-in.-o.d. casing. The BOP stack shall be tested using the cup tester. 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 A-V.
- 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. Surface Hole (26 in.) - mud.
- B. Intermediate Hole (17-1/2 in.) - mud, air, or aerated mud.
- C. Deep Hole (12-1/4 in.) - water, with intermittent volumes of mud.
- D. Final Hole (9-5/8 in.) - water, with intermittent volumes of mud.

Note: If unexpected hole and/or circulating problems occur, the University or its duly authorized representative may authorize the use of air, 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 (IADC).

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 directional survey.
- 2. Caliper log.
- 3. 3-D sonic log.
- 4. Density log.
- 5. Temperature log.

6. Induction - electric logs.
7. Gamma log.
8. Borehole televiewer.
9. Neutron log.
10. Deviation survey.
11. Core orientation.

TP-05. CASING AND HOLE SIZE

	<u>Hole Size (in.)</u>	<u>Casing Size (in.)</u>	<u>Approximate Depth (ft)</u>
Conductor	48	30 CMP	10
Surface	26	20	595
Intermediate	17-1/2	13-3/8	2200 - 2600
Deep	12-1/4	10-3/4	5400
Final	9-5/8	None	12 000 - 13 000

TP-06. INSTALLING CASING

A. Running Casing. The acceptance condition of hole prior to and during the running of any casing shall be the responsibility of the University. The procedure to be followed in handling and running of casing shall conform to accepted API practices and approved methods under actual field conditions. Contract casing crews will be used for running each casing string (except the conductor pipe).

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

The cementing services and cementing materials (including the concrete for the conductor pipe) are to be University furnished. All casing strings shall be cemented as directed by the University.

When the casing has been cemented, the shoe will be drilled out after a 16-h waiting period. The primary cement job will then be tested to a maximum pressure of 1500 psig, using the rig pumps.

TP-07. ALIGNMENT

The hole shall be checked for deviation by a directional survey instrument furnished by the University. These surveys shall be run in the drill pipe

on wireline or dropped (liquid only) when making a trip, or as otherwise directed by the University. 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 5-ft intervals unless otherwise directed by the University. The University shall provide all necessary equipment for collecting and labeling cuttings samples. The Contractor shall provide labor for collecting 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.

B. All cores are to be cut using a core barrel, diamond or roller-cutter carbide-insert core head, and direct fluid circulation. Orientation may be requested. The standard packed-hole assembly is to be used above the core barrel assembly during all coring operations.

TP-09. RECORDED MEASUREMENTS

The University will furnish a 4-channel rig-floor-mounted recorder to be connected to various sensors or other indicating equipment, to record weight on bit, rpm, circulating fluid flow rate, and torque.

TP-10. CORE ORIENTATION

Cored intervals in EE-1 will be oriented with equipment furnished by the University.

PART A-III

TENTATIVE DRILLING PROGRAM, EE-1

1. Preparation of Drilling Location. The Contractor shall prepare a suitable drill pad in accordance with the University grading plan, modified as necessary to accommodate the Contractor's specific drilling equipment. In addition to the drill pad, this location shall include a 250 000-gal reserve pit with an inflow ditch and an overflow drainage to the existing GT-2 reserve pit.

The existing all-weather access road will be maintained as necessary by the University.

2. Conductor Pipe. Using a large earth auger, drill a 48-in.-diam surface hole to a depth of approximately 10 ft. Set in concrete to ground level, a 10-ft length of 30-in.-diam corrugated metal pipe (CMP) to act as a conductor pipe for the subsequent drilling of the 26-in.-diam surface hole. To center the CMP in the bottom of the 48-in. augered hole, field weld four 9-in.-long steel spacer lugs (to be furnished by the University) to the bottom of the CMP prior to lowering into the hole.

3. Mobilize Rig on Previously Prepared Location.

4. Surface Cased Hole.

a. Drill a 26-in. hole to 600 $\pm$ ft, using mud as the circulating fluid.

b. Run and set 20-in.-o.d. buttress T&C casing at approximately 595 ft; cement by circulating cement to the surface.

5. Intermediate Cased Hole.

a. Drill a 17-1/2-in. hole from below the surface pipe (595 $\pm$ ft) to at least 2200 ft, and to approximately 2600 ft if the anticipated severe lost-circulation problems from 1900 to 2400 ft can be adequately overcome. Circulation will be by mud for the first 1900 ft, and by mud, air, aerated mud, or stiff foam below 1900 ft.

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

c. Run and set 13-3/8-in. casing 5 ft off the bottom of the drilled hole (may vary from 2200 to 2600 ft). Cement as directed. Install BOP (Blowout Preventer) on 13-3/4-in. casing head.

6. Deep Cased Hole.

a. Drill a 12-1/4-in. hole from below the intermediate casing string to approximately 5400 feet using water in combination with intermittent volumes of mud (mud sweeps) as the circulating fluid.

b. Core and conduct bottomhole temperature measurements as directed by the University.

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

d. Run and set 10-3/4-in. casing from the surface to approximately 5400 ft, or as advised by the University. Cement as directed.

7. Final Open Hole.

a. Below the 10-3/4-in. casing setting depth of 5400 ft, drill, with intermittent coring and bottomhole temperature measurements, a 9-5/8-in. hole to a final depth of 12 000 to 13 000 ft. (The final depth for EE-1 will depend primarily on the measured temperatures and temperature gradients -- the project objective is an EE-1 bottomhole equilibrium rock temperature of 250°C [482°F].)

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

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

PART A-IV

UNIVERSITY-FURNISHED ITEMS FOR EE-1

1. Access Road; 200 yards of existing Forest Service road, maintained as necessary. (The drilling location is only about 200 yards off State Highway 126 -- a two-lane paved road.)

2. Casing and Casing Materials.

a. 595 ft of 20-in.-o.d., 94-lb/ft, H-40 casing; buttress T&C.

b. 2200 to 2600 ft of 13-3/8-in.-o.d., 54.5-lb/ft, K-55 casing; short T&C (Range 3).

c. 4420 ft of 10-3/4-in.-o.d., 45.5-lb/ft K-55 buttress-thread casing with 11.25-in.-o.d. special-clearance couplings (Range 3).

d. 980 ft of 10-3/4-in., 45.5-lb/ft, K-55 casing with Hydril flush joints.

e. Centralizers for 20-, 13-3/8-, and 10-3/4-in. casing strings.

3. Directional Hole Surveying Equipment. Including two 8-in.-o.d. by 4-in.-i.d. Monel drill collars (with 6-5/8-in. regular threads).

4. Air Compressors and Related Equipment; as required for the drilling of the 17-1/2-in. hole.

5. Roller-Cutter Coring Equipment with Integral Stabilization; including an inner core barrel; a 9-5/8-in. hole stabilizer bit sub; and 8-in.-o.d. by 4-1/8-in.-i.d. outer core barrel; an upper cross-over sub; 9-5/8-in. roller-cutter core bits; etc.

6. Conventional Diamond Coring Equipment; including 5-1/4-in. by 9-5/8-in.-o.d. core bits, stabilized outer core barrel, inner core barrel, and related equipment; and the services of a coring engineer.

7. Cement and cementing services.
8. Mud, chemical additives, and mud engineering services.
9. Core Boxes and sample containers.
10. Packed-Hole Assemblies for 17-1/2-, 12-1/4-, and 9-5/8-in. holes.
 - a. Six-point bottomhole roller-cutter reamer.
 - b. Short (10 to 12-ft) large-diam drill collar.
 - c. Three-point string roller-cutter stabilizers.
 - d. Blade-type stabilizers and reamers as required.
11. Conductor Cable Sheave - standard Schlumberger-type sheave.
12. Drilling Recorder - four-channel daily chart recorder.
13. Inspection and recommendations for care and condition of drill pipe.
14. Water Tank Trailer 4500-gal capacity equipped with engine-driven pump and hose.

PART A-V

MINIMUM EQUIPMENT AND SERVICE REQUIREMENTS

TO BE FURNISHED BY THE CONTRACTOR, EE-1

Listed below are the minimum acceptable requirements for the Contractor drilling equipment.* This is not intended to be 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 550 000 lb gross nominal capacity capable of handling hook loads of 400 000 lb in air with eight lines. Combined racking capacity for 15 000 ft of 4-1/2-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 350 000 lb. It must accommodate the BOP equipment shown in Fig. A-1. The substructure minimum overall height should be sufficient to permit the installation of the blow-out preventer equipment shown in Fig. A-1, and listed in Item 15.

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

3. Drawworks. Minimum of 1000 horsepower total rated input, equipped with an appropriate-sized Hydromatic or electric (Elmaggo or equivalent) brake(s).

4. Drawworks Power. Minimum of two prime movers with a total 1000 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 - 250 tons.

7. Traveling Block and Hook - 250 tons.

8. Swivel - 250 tons.

9. Drill Line - 69 tons minimum breaking strength.

10. Steel Drill Collars (nominal 30-ft long). For 17-1/2- and 12-1/4-in. holes: sixteen 9-in.-o.d. drill collars; for the 9-5/8-in. hole: eighteen 8-in.-o.d. drill collars; with appropriate cross-over subs to Contractor's drill pipe and University-supplied reamers and stabilizers.

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 13 000 ft of either 4-1/4-in. (16.6 lb/ft) IF Grade G or equivalent, or 4-1/2-in. (20 lb/ft) IF Grade E or equivalent.

All drill pipe is to have been magnetically inspected (flux leakage method) within 30 days prior to the beginning of drilling on this hole and graded Class 2 (yellow band) 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. manifold (including valves) for air injection.

13. Rotary Hoses. One 55-ft by 3-in.-i.d., 2500-psi working pressure. (Standby hoses shall be available on 12-h notice.)

14. Mud Pump and Power. Two mud pumps are required. Primary pump: self-powered, 500-700 input HP at 8700 ft elevation above sea level, rated output of 350 gpm at 2000 psig. Secondary pump: may be rear-mounted to drawworks, output 600 gpm at 1000 psig.

*According to the AAQCD-API tentative system for classifying used drill pipe.

15. Blow-Out Preventer Stack. Shall be designed to operate at a temperature range of -20°F to $+300^{\circ}\text{F}$. (See Fig. A-1.)

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

b. Flanged spool, 12-in. by 12-in., Series 900 (3000-psi working pressure), with two 2-in. flanged side outlets.

c. 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 $+130^{\circ}\text{F}$. (Hydril Unit DCEPM-13-K80 and control manifold or equal.)

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

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

16. Light Plant. One standby 30-kW unit, to supply emergency rig power requirements. (Electric power is available to the EE-1 drilling site.)

17. Dog House and Trailer House.

18. Catwalk and Ramp.

19. Pipe Racks. Four sets of steel construction (8 units of 30 ft each).

20. Subs, for all Contractor and Contractor-furnished drill pipe, drill collars, bits, hole openers, reamers, stabilizers, etc.

21. Truck, 10-ton tandem, with winch and gin poles to handle Contractor and University-furnished equipment: at the drilling location or available on 8-hr notice to Contractor.

22. Steel Mud Pits. Three -- approximately 6 ft high by 8 ft by 30 ft equipped with two jets and two mud guns on each unit (including all valves and piping). Additionally, mud pit flexibility sufficient to include additional mud storage volume for cooling is required.

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

24. Hydrocyclones. Capacity of 380 gpm and capability of removing particle sizes down to 20 microns from fresh water. (These desanders are primarily for the granite drilling phase of EE-1: below a depth of 2400 ft).

25. Kelly. One 5-1/4-in. hexagon by 40 feet with a 3-1/2-in. bore; with bushings for 27-1/2-in. table, and all crossover subs.

Fig. A-1.
Blowout preventer stack for Hole EE-1.

26. Rotating Head. Shaffer, Grant, or equal for air drilling: shall be available on 36-h notice.

27. Choke Manifold. See Fig. A-1.

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

29. Water Storage. 1000-barrel capacity.

30. Covered Mud Storage. For 800 sacks of bentonite and chemicals.

31. Mouse Hole and Rat Hole Liners.

32. Lighting System for Rig.

33. Wire-Line Unit: power driven and equipped with 15 000 ft of 0.072-in. (minimum) line. Unit to have an accurate footage indicator.

34. Handling Tools, for Contractor's drill collars, drill pipe, cross-over subs, etc. Tools shall as required include tongs, safety clamps, spiders, slips, bails, elevators, wipers, etc.

35. Lubricants for Contractor's equipment.

36. Centrifugal Pump, portable, 100 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 for surface and intermediate hole; high-temperature lube for 9-5/8-in. hole.

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

43. Fishing Tools for all Contractor-furnished equipment, including a Bower or equal spiral grapple overshot sized for 8-in.-and 9-in.-o.d. drill collars.

44. Winterizing Equipment. Windbreaks, a forced-air or steam heating and heat distribution system, covered sheds for both mud pumps, etc.

PART A-VI

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, Stabilizers, and Hole Openers. (The University presently has most of the required bits, reamers, and stabilizers on hand.)
7. Casing Crews as Required.
8. Fishing Tools for all drilling assemblies: i.e. spiral-grapple over-shot, taper tap, bumper sub, mechanical jars, magnet, etc.
9. Additional Site Preparation, Road Maintenance, and Drainage as necessary.
10. Trash Removal and Hauling.
11. Fuel for Contractor equipment.
12. Post-Drilling Fracture Services, including required surface-set openhole packers, and service personnel.
13. Periodic Magnetic Inspection of drill string; at periods directed by the University.
14. Transportation for water.

PART A-VII

ANTICIPATED SUBSURFACE INFORMATION FOR EE-1

These generalized sections are based on the stratigraphic section penetrated in the adjacent exploratory hole GT-2, approximately 600 ft to the south.

	<u>Thickness (ft)</u>	<u>Depth (ft)</u>
<u>Bandelier Tuff</u>	360	360
Tuff, gray, moderately welded, rhyolytic; crystals, crystal fragments, and rock fragments in an ash matrix.		
<u>Paliza Canyon Formation</u>	50	410
Andesites and basaltic andesite breccia, with interbedded sands and gravels.		
<u>Abiquiu Tuff</u>	50	460
Sandstone, light gray, tuffaceous friable.		

	Thickness (ft)	Depth (ft)
<u>Abo Formation</u> (Permian Red Beds)	780	1240
Shale, siltstone and fine-grained sandstone, some clay lenses; predominantly red to dark red in color, with lenses of white to gray shale and clay; a few thin beds of limestone near the base.		
<u>Magdalena Group</u>		
<u>Madera Limestones</u>		
Upper limestone member consists of limestone alternating with gray and red shales and sandstone, arkosic.	610	1850
Lower limestone member consists of dark gray limestone and thin lenses of white to gray shale and fine-grained sandstone.	115	1965
Shale member (not described in area) consists of dark gray shale and clay with thin lenses of dense siliceous limestone.	180	2145
<u>Sandia Formation</u>		
Upper clastic member: limestone, gray, with lenses of dark gray shale and fine-grained sandstone ranging from light gray to light green.	205	2350
Lower limestone member: limestone, dark gray, siliceous, dense.	55	2405
<u>Precambrian Rocks</u>		below 2405
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.		

PART A-VIII

UNIT PRICE SCHEDULE FOR ENERGY EXPERIMENT HOLE NO. 1

Item Number	Description	Estimated Quantity	Unit	Unit Price	Estimated Amount
1	Mobilization	1	Job	\$ _____	\$ _____
2	Standard hourly rate operations				
	a. With drill pipe	3720	Hr	\$ _____	\$ _____
	b. Without drill pipe	600	Hr	\$ _____	\$ _____

<u>Item Number</u>	<u>Description</u>	<u>Estimated Quantity</u>	<u>Unit</u>	<u>Unit Price</u>	<u>Estimated Amount</u>
3	Standby-Secured	0	Hr	\$_____	\$_____
4	Demobilization	1	Job	\$_____	\$_____
5	Optional demobilization hourly rate operations	~120	Hr	\$_____	\$_____
6	Special items and services*				\$~396 000
	<u>TOTALS</u>	(180 days)			\$_____

*Based on the GT-2 experience of an average \$2200/day for Special Items and Services.

APPENDIX B

SPECIFICATIONS OF SIGNAL DRILLING COMPANY DRILLING RIG NO. 5

Rig	National 80 drawworks with 3-engine compound, 2-pump drive and 46-in. hydromatic brake.
Power	3 - Waukesha F2895 diesel engines, 1500 continuous HP and 1800 IHP @ 1100 rpm equipped with air-x-changers.
Pump No. 1	National G-1000-B 1000 HP w/Mattco fluid end.
Pump No. 2	National C-350 (7-3/4-in. by 18-in.) 600 HP Mattco fluid end.
Mast	133-ft Lee C. Moore 700 000-lb capacity with 14 ft by 9 ft step-down substructure.
Drill pipe	13 000-ft 4-1/2-in.-o.d. Grade E with 6-in.-o.d., 4-1/2-in. XH tool joints hard-banded.
Drill collars	As required. 5-3/4-in.; 6-1/4-in.; 6-1/2-in.; 7-in.; 8-in.; o.d.
BOP equipment	1 - 10-in. or 12-in. Series 900 Shaffer hydraulic double gate or cameron "QRC" as required. 1 - 10-in. or 12-in. Series 900 GK Hydril.
Mud tanks	3 - Steel mud tanks 750-bbl total capacity with 4-tier RVS shaker.
Light plant	1 - 150-kW (ac) generator. 1 - 30-kW (ac) generator.
Light string	1 - String Rig-A-Lite vapor-proof lights complete with vapor-proof flood lights.
Tanks	1 - 500-bbl skidded water tank.

Housing	Rig, engines and pumps completely enclosed in steel housing. 1 - 7-ft by 24-ft steel doghouse. 1 - 7-ft by 14-ft storage house. 1 - 8-ft by 20-ft steel mud house. 1 - 26-ft trailer house.
Boiler	1 - 100-HP steam boiler heating unit, skidded and housed.
Auxiliary equipment	1 - Bell automatic driller. 1 - Mud desilter independently powered w/low pressure mud mixing system. 1 - 80-gal Hydril accumulator closing unit in steel housing. 1 - Automatic crown stopper.

Rig can efficiently drill to 14 000 ft with 4-1/2-in. drill pipe or 17 000 ft with 3-1/2-in. drill pipe.

APPENDIX C

SPECIFICATIONS FOR CEMENTING SERVICES FOR EE-1

1. Cementing 20-in. Casing

The cementing services contractor will furnish all services, personnel, equipment, cement, and other related materials required to cement 600 ft of 20-in.-o.d. line pipe in a 26-in.-diam hole. The cement will be circulated through the annulus to the surface with a plug being run between the cement slurry and the displacing water.

The University will furnish the casing, fitted with centralizers and a casing shoe on the bottom. The University will also furnish all required water for cementing operations.

2. Cementing 13-3/8-in. Casing

The cementing services contractor will furnish all services, personnel, equipment, stage cementing plugs, cement, and other related items required to cement 2600 ft of 13-3/8-in.-o.d., K-55, 54.5-lb/ft, Range 3 casing in a 17-1/2-in. drilled hole.

The University will furnish the casing, fitted with sufficient stabilizers, a casing shoe on the bottom, and a float collar between the first and second joints. The University will also furnish stage-cementing collar(s) and all required water for cementing operations.

The 17-1/2-in. hole will be drilled through the previously set and cemented 20-in. casing, and will extend through approximately 700 ft of

Permian-age Abo Formation and 1100 ft of Pennsylvanian-age Madera Limestone. The bottom 200 ft of the hole will be in the Precambrian-age granitic rocks. It is anticipated that the cementing operations will be conducted in stages with the first stage being from the bottom of the hole to a lost-circulation in the overlying limestone. In the final stage, the cement will be circulated through the annulus to the surface, with a plug being run between the cement slurry and the displacing water. The water hole temperature for the first stage cementing is anticipated to be approximately 100°C (212°F).

APPENDIX D
DRILL BIT RECORDS FOR THREE DEPTHS

Figures D-1 through D-3 show drill bit records for three depths: 6874 ft, 9766 ft, and 10 053 ft.

CONTRACTOR Signal Drilling Company		TRG NO: 5	DIAMETER: N80	Q.C. K. I.D. x LENGTH 8-3/4 x 2-1/2 x 500	MO. / DAY / YEAR ____/____/____	CR DRILLERS:
COMPANY: LASL-1		FIELD: Fenton Hill	DEPTH & R.P. RATING: 1500	SPUD: ____/____/____	U.S.: ____/____/____	
WELL NAME: EE		WELL NO: 1	PUMP MAKE 1: National	INTER: ____/____/____		WATER SOURCE:
STATE: New Mexico		COUNTY: Sandoval	PUMP MAKE 2: National	DRILL PIPE: 6 1/2 XII	FUEL SOURCE:	
SEC: 13	T-SHIP 19N	RANGE: 2E	MUD TYPE: -	T.O. TYPE: -	T.O. TOTAL DAYS: ____	TOTAL ROT. HRS.: ____

MFG	RUN NO	SIZE	TYPE	SERIAL NO	JET'S - 32 nds REC. R. OF R.O.			DEPTH OUT	FEET	HOURS	FEET PER HOUR	WT. 1000 LBS.	R.P.M.	PUMP PRESS	PUMP NO LINER SIZE	MUD PROPERTIES						VER DEV	DULL COND. 1/4 1/8				REMARKS	DATE	DEPTH
					1	2	3									WT.	WL	EV	PP /YP	% SOL	T		D	G	Rd				
SEC	1	17-1/2	S-88	530055	24	24	24	608	608	30.5	19.9	60	40	900			9.3					3	1	1	I				
SEC	-	26	HO	66675	24	24	24	584	584	50	9.7	30	40	650			9.5					3	1	2	I				
HTC	2	17-1/2	OSC3A	BJ340	OPEN			741	133	13.7	11.4	50	40	400			9.1					2-1/2	1	1	I				
SEC RR	17-1/2	S88	RR1		16	16	16	862	121	7.7	15.6	65	40	500			9.3					2-1/2	1	1	I				
HTC RR	17-1/2	OSC3A	RR2		18	18	18	1403	541	43.7	12.3	65	40	750			9.4					2-1/2	2	3	I				
SEC RR	17-1/2	S88	RR1		16	16	16	1680	277	47.7	5.8	65	40	800			9.3					2	2	0	I				
HTC	3	17-1/2	44J	JS022	16	16	16	2130	450	104	4.3	70	40	800			9.1					1-1/2	1	2	I				
HTC	4	17-1/2	RG7J	2E582	OPEN			2166	36	14.7	2.4	70	40	400			9.3					-	1	1	I				
SEC RR	17-1/2	S88	RR1		22	22	22	2333	167	27.5	6.1	70	40	800			9.3					1-3/4	3	4	I				
HTC RR	17-1/2	44J	RR3		16	16	16	2358	25	4.5	5.5	70	40	1300			9.1					-	1	1	I				
HTC RR	17-1/2	OSC3A	RR2		OPEN			2384	26	3	8.6	70	40	0			Water					-	4	4	I				
HTC RR	17-1/2	44J	RR3		"			2431	47			70																	
HTC	5	12-1/4	ODV	RR		"		2431	Drilling stage collars																				
STC	6	12-1/4	Q9J	PE842	14	14	14	2785	354	71	5.0	70	40	1000			Water					-	6	7	I				
STC	7	12-1/4	Q9J	PH011	16	16	-	3123	338	57	6.0	70	40	1300			"					3/4	6	8	I				
SEC	8	12-1/4	H100	556504	16	16	-	3773	650	107.5	6.0	70	40	1300			"					2	8	8	1/2				
STC	9	12-1/4	Q9J	PE754	16	16	-	4164	391	73.7	5.3	70	40	1300			"					2-1/2	7	8	1/2				
SEC	10	12-1/4	H100	556495	13	13	13	4916	752	96.2	7.8	70	40	1350			"					4	6	7	1/2				
STC	11	12-1/4	Q9J	PH237	16	16	-	5266	350	68	5.1	70	40	1000			"					-	7	7	1/2				
SEC	12	12-1/4	H100	566995	14	14	-	6087	821	106	7.7	70	40	1400			"					7	6	8	1/8				
STC	13	12-1/4	Q9J	NS890	14	15	-	6420	333	27	12.3	70	40	1300			"					6-1/2	7	8	1/2				
STC	14	12-1/4	Q9J	NS458	14	15	-	6420	Reaming to run casing																				
SEC	15	9-7/8	H10JP	590673	15	15	-	6490	70	8.2	8.5	45	40	1500			"					5-3/4							
SEC	-	9-7/8	H10JP	RR15	15	15	-	6874	384	41.7	9.2	50	40	1500			"					6	5	6	1/8				

Fig. D-1.
Drill bit record to 6874-ft depth.

CONTRACTOR				FIG NO:				DRAWINGS:				OD X ID X LENGTH				MO / DAY / YEAR				DR DRILLERS:			
COMPANY				FIELD				DEPTH & TIME RATING:				D.C.:				SPUD:							
LASL-2												X X X				/ /							
WELL NAME				WELL NO				PUMP MAKE 1:				X X X				U.S.:				/ /			
STATE				COUNTY				PUMP MAKE 2:				X X X				INTER:				/ /			
SEC				T-SHP				MUD TYPE:				DRILL PIPE:				T.D.:				WATER SOURCE:			
				RANGE								T.J. TYPE:				TOTAL DAYS:				TOTAL ROT. HRS:			
																				FUEL SOURCE:			

MFG	PUMP NO	SIZE	TYPE	SERIAL NO	JETS - 3/4 IN (IN. IN. IN.)			DEPTH OUT	FEET	HOURS	FEET PER HOUR	WT. 1000 LBS.	R.P.M.	PUMP PRESS.	PUMP INCH	MUD PROPERTIES				VER. DEV.	DULL COND. 1/4 IN				REMARKS	DATE	DEPTH			
					1	2	3									WT	WL	EV	PP	Yp	COL		T	G	O	IN				
STC	-	9-5/8	98CJA	RN287	-	-	-	6886	12	2.7	4.4	25	40	500		Water													Core	
SEC	16	9-7/8	H10JP	590838	15	15	-	6886	Drilling		cement; ream core hole.																			
SEC	17	9-7/8	H10JP	590842	20	20	20	6951	65	3	21.7	15	250																Dynadrill	
SEC	-	9-7/8	H10JP	RR17	15	15	15	7033	82	11.7	7.0	50	40	1500									6	3	3	I				
SEC	18	9-7/8	H10JP	590839	20	20	20	7172	139	8.7	15.9	15	250																Dynadrill	
SEC	-	9-7/8	H10JP	RR17	15	15	15	7247	75	8.5	8.8	50	40	1550																
SEC	19	9-7/8	H10JP	590669	16	16	16	7387	140	5	28	40	250									7-3/4							Dynadrill	
SEC	-	9-7/8	H10JP	RR17	15	15	-	7387	0																				Reaming	
SEC	20	9-7/8	H10JP	590836	14	14	-	7714	327	31.7	10.2	60	40	1600								6-3/4	8	8	1/2					
SEC	21	9-7/8	H10JP	590840	14	14	-	8060	346	38.2	9.3	65	40	1600								6-1/2	7	8	1/8					
SEC	22	9-7/8	H10JP	590837	14	14	-	8200	140	24.7	5.6	55	40	1600								6-1/2	5	6	1/8					
SEC	23	9-7/8	H10JP	590671	16	16	16	8313	113	4.7	23.8	20	250	900								4	8	8	1/2					
SEC	-	9-7/8	H10JP	RR22	13	13	13	8330	17	1.5	11.3	55	40	1400								5-1/2	6	6	1/8					
SEC	24	9-7/8	H10JP	590670	14	14	-	8571	241	26.7	9.0	55	40	1600								5-3/4	4	4	1/8					
SEC	25	9-7/8	H10JP	590674	14	14	-	8826	255	31.7	8.0	40	40	1600								5-1/2	6	6	1/8					
SEC	26	9-7/8	H10JP	590672	14	14	-	8991	165	23.2	7.2	35	40	1600								5	4	4	I					
SEC	27	9-7/8	H10JP	621149	14	14	-	9168	177	25.2	7.0	35	40	1600								4-1/2	4	4	I					
SEC	28	9-7/8	H10JP	621153	14	14	-	9437	269	40.5	6.6	35	40	1600								4	6	8	I					
SEC	29	9-7/8	H10JP	621151	14	14	-	9575	138	17.7	7.8	45	40	1600								3-3/4	4	5	I					
SEC	-	9-7/8	H10JP	RR27	14	14	-	9575	0																				Clean out	
SEC	30	9-7/8	H10JP	621401	16	16	16	9643	68	3	22.6	30	250	800								-	5	8	I				Dynadrill	
SEC	31	9-7/8	H10JP	621152	16	16	16	9690	47	1.2	31.3	30	250	800								-	7	8	I				Dynadrill	
SEC	-	9-7/8	H10JP	RR27	14	14	-	9690	0	Drilling		cement																	Clean out	
SEC	32	9-7/8	H10JP	621150	16	16	16	9766	76	2	38	20	250	1100								5	7	6	1/2				Dynadrill	

Fig. D-2.
Drill bit record to 9766-ft depth.

Fig. D-3.
Drill bit record to 10 053-ft depth.