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THERMAL POWER COMPANY
San Francisco Office

Project Title: Cascade Geothermal Drilling

CLACKAMAS 4800-FOOT THERMAL GRADIENT HOLE

Cooperative Agreement No. DE-FC07-85ID12614

FINAL TECHNICAL REPORT
30 September 1987

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1 October 1987

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RE: Cooperative Agreement
No. DE-FC07-851D1D12614
Final Technical Report

Dear Ms. Prestwich:

Thermal Power Company herewith transmits 4 copies of the Final Technical Report for the 4800-foot Clackamas Thermal Gradient Hole. Additional single copies were separately mailed to key persons as shown below.

We enjoyed participating in the Cascade Geothermal Drilling Project, as a mutually beneficial opportunity created by DOE. Your skilled management in this joint work was especially appreciated.

Very truly yours,

W. L. D'Olier
Vice President
Geothermal Exploration

0037S/pg3/ao

cc: Hoyles - DOE
Wright - UURI ✓
Reed - DOE
Cole - Chevron

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EXECUTIVE SUMMARY

Thermal Power Company in a Cooperative Agreement with the United States Department of Energy (DOE), has completed a 4800-foot (1463 m) thermal gradient hole as part of DOE's Cascades Geothermal Drilling Project. This hole, referred to as the Clackamas Thermal Gradient Hole (CTGH)-1, is located 10 miles (16 km) north of Mt. Jefferson along the axis of the High Cascades in Marion County, Oregon. CTGH-1 tested the basis of the Clackamas geothermal prospect which lies between the Tertiary Western Cascades and the axis of the Quaternary High Cascades. The hole was sited at a major structural intersection associated with a low-resistivity anomaly, approximately 5 miles (8 km) northwest of the Olallie Butte summit. This association was interpreted as a locus of upwelling geothermal fluids.

Maximum bottomhole temperature in CTGH-1 is 206°F (97°C) at 4800 feet (1463 m). The "rain-curtain" effect in the High Cascades extends to about 1700 feet (518 m) in this hole, and is most prominent in the 75 to 1200-foot (23 to 366 m) depth range. Below 1700 feet (518 m), a conductive temperature gradient of 4.5°F/100 feet (82°C/km) persists to total depth. The hole was found to be relatively tight and dry. Fracturing is present but apparently unconnected to any significant hydrologic regime. Heat flow studies by Blackwell and Steele (in press) have shown that the bottom portion of CTGH-1 below the "rain-curtain" effect, displays a heat flow value of 115mWm^{-2}. This observation is consistent with the earlier hypothesis by Blackwell et al. (1982) that the axis of the High Cascades in Oregon is associated with a heat flow greater than 100 mWm^{-2}. Downward projection of the CTGH-1 temperature data suggests that at depths greater than 9000 feet (2743 m), temperatures in excess of 400°F (205°C) could be present. These thermal conditions indicate that the potential for a commercial-grade hydrothermal system in the Clackamas prospect is present.

CTGH-1 was spudded on 7 June 1986 and completed on 7 September 1986. It was rotary drilled from surface to 527 feet (161 m) and then diamond cored with a 10-foot (3 m) core barrel to total depth. No significant drilling or coring problems were encountered except for a parting of the HX rods (3.94" OD) at 823 feet (251 m) while coring at 4205 feet (1282 m). NX-size (2.875" OD) coring assembly and rods were used for the remainder of the 4800-foot (1463 m) hole. Fluid circulation was maintained during rotary drilling but a continuous, average daily water loss of 7000 gallons (26,498 liters) persisted during coring. Core recovery was virtually 100%. The mechanical condition of the hole is such that deepening to a 6000-7000 foot (1829 - 2134 m) total depth could be achieved with NX rods. Total cost of drilling/coring CTGH-1 and all associated data acquisition by Thermal Power Company was approximately $450,000. This expenditure does not include the 4205 feet (1282 m) of HX rods left in the hole or Thermal Power Company staff time. CTGH-1 will be retained in its current suspended state for future evaluation, including possible deepening.

The hole penetrated 1200 feet (366 m) of Quaternary High Cascades rocks, 1500 feet (457 m) of probable Pliocene rocks, and bottomed in a 2100-foot (640 m) section of possible Mid-Miocene basaltic-andesite. The rocks in CTGH-1 are altered to zeolite grade only, indicating that they have not been subjected to a high-temperature hydrothermal event. Barger (1987) reports that the

secondary minerology in the hole is compatible with the existing low-temperature diagenetic conditions. Acquisition of a full suite of borehole geophysical logs below 517 feet (158 m) was impaired by the presence of 4205 feet (1282 m) of HX rods and a relatively high bottom hole temperature. Attempted cooling, by pumping copious amounts of cold water into the hole was precluded by the small hole diameter and lack of significant permeability at depth. Rapid thermal rebound occurred. The suite of logs obtained do show a section of generally low-resistivity (5 ohm-meters) from 4205 to 4800 feet (1282 to 1463 m); the neutron density log in the same depth interval suggests very limited hydrogen content (i.e., water and/or clay alteration). The low borehole resistivity validates the interpreted areal resistivity anomaly, which was one of the criteria for drill site selection. However, this low-resistivity anomaly cannot be attributed to a high-temperature geothermal system as evidenced by the low bottom hole temperature and low grade alteration mineralogy. It is suspected that the low-resistivity anomaly is due to the presence of minor amounts of clay alteration.

DOE will be conducting detailed scientific studies on the hole and surrounding area through its various subcontractors: Southern Methodist University (SMU), Oregon State Department of Geology and Mineral Industries (DOGAMI), and University of Utah Research Institute (UURI). Heat flow studies will be conducted by Dr. Blackwell (SMU). Some initial results have been presented above. A quantitative analysis of the well logs will be done by UURI. It is expected that they will document the relationship between clay alteration and the resistivity/neutron density logs. DOGAMI will be undertaking detailed stratigraphic correlations of CTGH-1 with surrounding holes and a deep well (8060' (2457 m) total depth) at Breitenbush Hot Springs. Additionally, the U.S. Geological Survey will perform other scientific studies in the region. An alteration minerology study of CTGH-1 has been recently completed by Bargar (1987). Geologic field mapping in the Clackamas region by Dr. D. Sherrod and Mr. R. Conrey is in progress. An overall scientific synthesis of all available data on the region will be conducted by DOGAMI which will publish an open file-report on the geothermal system model for the Brietenbush-Olallie Butte area.

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INTRODUCTION

On 30 September 1985, Thermal Power Company (Thermal) entered a Cooperative Agreement (No. DE-FC07-85ID12614) with DOE to:

(1) drill/core and complete a thermal gradient hole to about 5000 feet (1524 m) total depth in Section 28, Township 8 South, Range 8 East, Willamette Meridian, Marion County, Oregon;

(2) collect a selected suite of geoscientific data;

(3) release all collected data to the public; and

(4) prepare a technical report on the activities conducted.

All Federal, State and County permitting requirements for this operation were the sole responsibility of Thermal. A Plan of Exploration was filed with the U. S. Bureau of Land Management (BLM), Oregon Department of Geology and Mineral Industries (DOGAMI) and the Marion County Planning Department (D'Olier, 1986; Iovenitti, 1985 and 1986). Additionally, Thermal was required to submit a variety of project plans to DOE describing various facets of the operation. These are all referred to in the appropriate sections below except for the Project Management Plan (Thermal Power Company, 1985a). This Technical Report completes Thermal's obligations under Cooperative Agreement No. DE-FC07-85ID12614.

DOE's objective under this agreement was to obtain data for the characterization of the deep hydrothermal regime in the Cascades volcanic region in order to better define its geothermal resource potential. The depth and location of the thermal gradient hole were designed by Thermal to test the basis of the Clackamas geothermal system exploration model developed by Chevron Resources Company. A concise summary of this model follows. For additional details the reader is referred to Thermal's proposal to DOE for this operation (Thermal Power Company, 1985b).

Exploration Model

The Clackamas geothermal prospect lies between the Tertiary Western Cascades and the crest of the Quaternary High Cascades, approximately 10 miles (16 km) north of Mt. Jefferson (Figure 1). Regionally, the prospect occurs in the north-central portion of a 100 mWm^{-2} heat flow anomaly in Oregon (Blackwell et al. 1982), at the northern terminus of a shallow depth, 3 to 6 miles (5 to 10 km), to the Curie Point isotherm (Foote, 1985), and at the northern end of the contiguous Quaternary volcanic field in Oregon. Limited geological and petrochemical data suggest that the Olallie Butte polygenetic volcanic field may represent a growing stratovolcano (White, 1982; Thermal Power Company, 1985b). The heat flow anomaly allowed Blackwell et al. (1982) to postulate a large, intense heat source at a 4 to 6 miles (7-10 km) depth which is thought to be formed by a zone of partial melt resulting from magma generated by the subduction of the Juan de Fuca Plate beneath the North American Plate (Figure 1). Heat to generate a convective geothermal system in the prospect area is considered to be derived from this zone of partial melt and a relatively shallow magmatic heat source under the Olallie Butte volcanic field.

The only known geothermal surface manifestations in the area of this prospect occur at Austin and Breitenbush Hot Springs in the Western Cascades (Figure 2). These springs show among the highest surface temperatures, 187°F (86°C), and the hottest estimated reservoir temperatures, 350-374°F (177-190°C), of any hot springs in the Cascade Range (Mariner, 1985). Their occurrence is thought to be controlled by faulting and topography. These springs are interpreted to represent outflow from a geothermal system underlying the High Cascades.

Telluric-magnetotelluric surveys conducted at the prospect, revealed three discontinuous, low-resistivity anomalies coinciding with zones of structural intersection (Figure 2). Two of the anomalies are open in the direction of the aforementioned hot springs. The low resistivity areas were interpreted to reflect zones of upwelling geothermal fluids and/or the hydrologic flow path from the region of upwelling to the surface discharge at Austin and Breitenbush Hot Springs.

A total of 10 shallow thermal gradient holes about 500 feet (152 m) in depth, and one 1500 feet (457 m) intermediate depth hole were drilled in the region by Chevron Resources Company and/or Eugene Water and Electric Board (EWEB). Sunedco drilled a deep exploratory well, Breitenbush 58-28, to a total depth of 8060 feet (2457 m) in the Breitenbush Hot Springs area. The locations of these holes and the well are shown in Figure 2. Temperature-depth plots of these data are presented in Figure 3. Temperature gradients in the vadose zone are isothermal or reversed. Gradients below this zone range from 1-4°F/100 feet (18-73°C/km). The intermediate hole displayed a 3°F/100 feet (55°C/km) thermal gradient at bottom which Youngquist (1980) reports as average for this area of the Cascades. The approximate 250°F (121°C) maxima found in the Breitenbush 58-28 occurs in a shallow aquifer of the lower Miocene-upper Oligocene Breitenbush Formation. The aquifer dips to the east in the direction of the Clackamas prospect (Mr. A. Waibel, oral commun. 1985).

A conceptual exploration model of the Clackamas geothermal system utilized to site CTGH-1 is shown in Figure 4. Meteoric water infiltrating through the crest of the High Cascades is heated by both the regional heat flow generated by the zone of partial melt at 4 to 6 miles (7-10 km) and by a shallower magmatic heat source postulated to be underlying Olallie Butte. Thermal fluids rise along permeable structures, such as zones of structural intersection, and charge permeable stratigraphic horizons. These fluids migrate updip to the north and west along the permeable horizons to discharge in the deeply dissected stream valley of the Western Cascades at Austin and Breitenbush Hot Springs.

Exploration Target

To test the exploration model, a drill site was selected in the NW 1/4, SE 1/4, Section 28, Township 8 South, Range 8 East in Marion County, Oregon. This site is proximal to a major fault intersection, as well as to Olallie Butte, and is within an areally large, low-resistivity anomaly (Figure 2). It was inferred that the principal upwelling zone of highest temperature geothermal fluids would be in the Olallie Butte area. A 5000-foot (1524 m) Clackamas thermal gradient core hole (CTGH-1) was proposed to DOE in order to evaluate a resistivity minimum of 2.2 ohmmeters at about 5300 feet (1615 m), as indicated by a one-dimensional Bostick inversion of a nearby telluric-magnetotelluric station (Figure 5).

Other factors influencing site location were of an environmental, institutional and logistical nature. These are not treated within this technical report other than stating that the hole was sited on a clear cut parcel, and on an existing Federal geothermal resources lease within the environmentally assessed Mt. Hood National Forest. The reader is referred to the Project Institutional Plan submitted to DOE (Thermal Power Company, 1985c) for details.

DRILLING/CORING AND COMPLETION

CTGH-1 was spudded on 7 June 1986 and completed at a 4800-foot (1463 m) total depth on 7 September 1986. This operation was executed according to the Project Drilling Plan submitted to and accepted by DOE (Thermal Power Company, 1985d). Appendix 1 provides the Drilling and Completion History for the hole and the Completion Reports submitted to the BLM and DOGAMI. Illustrated in Figure 6 is the depth penetration profile for CTGH-1. The complete set of daily drilling reports is available through the University of Utah Research Institute (UURI). Discussed below are the salient features of the mechanical aspects of the CTGH-1 operation.

The hole was rotary drilled with a Boyles Bros. truck-mounted rotary rig from surface to 526 feet (161 m). At 35 feet (11 m), a 10-3/4" surface conductor was cemented within a 12-1/4" hole. An 8-3/4" hole was drilled to 517 feet (158 m). Geophysical borehole logs (Table 1) were run prior to cementing 7" surface casing, which was run only to 488 feet (149 m) where it became stuck. A LARKIN casing head was welded to the 7" casing; the BOPE was installed and tested. Representives of the BLM observed and approved the test.

The rotary rig was replaced with a Boyles Bros. CP 50 core rig. The hole was cleaned to 517 feet (158 m) and drilled to 527 feet (161 m) with a 6" bit. A 4.5" core guide string was run to 526 feet (160 m) and hung from the 7" casing head. HX core (3.937" diamond corehead, 2.5" core) was obtained from 527 to 4205 feet (161 to 1282 m) where coring was interrupted by failure of the HX rods. An evaluation found the HX rods parted at 823 feet (251 m). Coring was resumed utilizing NX rods (2.875" diamond corehead 1.9" core) to 4780 feet (1457 m). At this depth, a U. S. Forest Service order was issued to Thermal to completely shutdown all rig operations because of a Class E fire risk. While an exception to this order was sought, the hole was cored to 4800 feet (1463 m). No exception was granted. Consequently, coring operations were shutdown for 16 days before operations were resumed.

During this shutdown, a Pruett wireline temperature/pressure survey was conducted with Forest Service approval. These data, along with the geological information obtained on the hole, indicated that the objective of CTGH-1 in evaluating the Clackamas exploration model was achieved by the 4800 foot (1463 m) total depth. DOE concurred with this assessment and the hole was completed at this depth.

Hole completion consisted of running geophysical borehole logs (Table 1), installing a 1-1/4" plate flange onto the LARKIN casing head, rigging down, cleaning the site and releasing the rig. The abovementioned plate flange contains a 3" full-opening gate to allow access into the hole for temperature/pressure surveys. The CTGH-1 completion configuration is shown in Figures 7 and 8.

Mechanical Hole Problems

Other than the HX core rods parting at 823 feet (251 m) while coring ahead at 4205 feet (1282 m), no significant mechanical hole problems were encountered during this operation. The coring operation was very successful with nearly 100% core recovery. The mechanical integrity of the hole suggests that it could be cored to 6000-7000 feet (1829 - 2134 m) with the NX rods.

DATA COLLECTION PROGRAM

The data collection program consisted of on-site selected geoscientific data acquisition herein referred to as geologic logging and geophysical borehole logging. The former was conducted by Mr. D. Goodwin and Ms A. McDannel with lithologic assistance from Columbia Geoscience. The latter was performed by COLOG, Inc. For details, the reader is referred to the Project Data Collection Plan submitted to DOE (Thermal Power Company, 1985e).

Geologic Logging

This activity entailed collecting, handling and cataloging retrieved rock samples (both cuttings and core), preliminary lithologic descriptions and maintaining a log of (1) drilling temperatures, (2) depth penetration rate, (3) borehole fluid (water) level, (4) lost circulation and (5) relevant comments. All these data are provided in Appendix 3 which also contains the preliminary review of the secondary mineralogy by Columbia Geoscience. Daily geologic reports, a detailed (1" = 5') core description log, a detailed cutting description log (at 20' intervals) and a core recovery log maintained by Thermal on CTGH-1 can be obtained from UURI. Discussed below are the highlights of these data sets.

Lithology

Figure 9 is a generalized depth profile of the lithologies encountered in the hole as defined by the drill site geologists. Below a 40-foot (12 m) cover of glacial till, a High Cascades basalt/basaltic-andesite section extends to 1230 feet (375 m). A 258-foot (79 m) section of dacite occurs from 854 to 1138 feet (260 to 347 m). Underlying the High Cascades rocks is a 1496-foot (456 m) section of andesite/basaltic-andesite with volcanic and volcanoclastic rocks tentatively identified as the Outerson Formation. A thick basaltic-andesite section persists to total depth. This lower section is thought to be mid-Miocene in age (Mr. A. Waibel, oral commun., 1986) and is either the Elk Lake or Sardine Formation (see Priest et al., 1983). Some discrepancy exists in lithologic identification between the drillsite geologists and Columbia Geoscience. The interested reader is referred to the detailed lithologic descriptions that will be prepared by UURI and DOGAMI. Tectonically induced fracturing, brecciation and faulting is common throughout the hole; much of it is interpreted to be vertically oriented. Secondary mineralogical alteration is present in the hole but does not exceed zeolite grade. Barger (1987) reports the secondary minerology in the hole to be consistent with low-temperature diagenetic processes. There is no lithologic evidence of a significant hydrothermal event in CTGH-1.

Drilling Temperature

Drilling temperatures monitored during the operation consisted of drilling fluid (mud) in or out temperatures and/or maximum borehole temperatures obtained with maximum recording thermometers (MRT) during core recovery. The MRTs were attached immediately above the core barrel recovery latch. MRT temperatures increased with depth below 2000 feet (610 m) at an average 4.6°F per 100 feet (84°C per km) to a maximum of 197°F (91°C) at 4800 feet (1463 m), Figure 10. The MRT profile is suggestive of local permeability at several intervals correlating with a significant daily fluid loss in the hole (discussed below). However, a temperature/pressure survey conducted by Pruett Wireline Industries, nine days after the coring operation was shutdown by the U. S. Forest Service (see previous discussion), shows a conductive thermal gradient of 5.1°F/100 feet (94°C/km) from approximately 2600 to 4800 feet (793 to 1463 m), Figure 10. The pressure profile shows normal hydrostatic conditions in CTGH-1. If the permeable zones indicated by the MRT data are water-bearing aquifers, then these aquifers are in thermal equilibrium with the surrounding rock mass. Permeable zones containing through flowing geothermal fluids are not indicated.

Penetration Rate

The upper portion of the hole, rotary drilled from surface to 517 feet (158 m), had an average penetration rate of 35 feet (11 m) per hour in the interval from 517 to 4800 feet (158 to 1463 m) cored at a relatively uniform rate of 10 feet (3 m) per hour on average (Figure 6). No systematic relationship between penetration rate, rock type and/or degree of fracturing was discerned.

Water Level and Lost Circulation Zones

Water level measurements in the borehole were taken daily during the drilling/coring operation. During rotary drilling, the water level was indicated by circulated fluid returns. Full fluid return was achieved throughout this phase of the activity except for two instances. The first instance occurred when the fluid level dropped to 80 feet (24 m) below the surface (bs) after a 12-hour period of no activity at 220 feet (67 m) drilled depth. An addition of 300 gallons (1136 liters) of water was required to bring the fluid level to the surface. The second instance consisted of minor occurrences of lost circulation at 400 and 425 feet (122 and 130 m).

During coring, water level was measured daily, at the morning crew change, after the hole had remained static for 15 minutes. The data obtained must be interpreted with caution because (1) they may not represent the equilibrium water level for the depth drilled; and (2) they are sensitive to other factors besides the potentiometric surface of the aquifers drilled (e.g., the mechanical obstructions in the annulus between the wall rock and drill rods could dramatically affect borehole water level). This mechanical phenomenon may explain the difference in water level measured with and without drill rods in the hole at 1775 and 3720 feet (541 and 1134 m), see Appendix 2. The entire coring activity was conducted without returns except for a short interval between 4206 and 4226 feet (1282 and 1288 m). Listed below are average water level depths in the hole as coring proceeded.

Depth Interval (feet)	Water Level (feet, below surface)
517 - 1500	30 - 45
1600 - 1725	15 - 20
1800 - 4206	75
4226 - 4800	45

Water loss in the cored portion of the hole averaged 7000 gallons (26,498 liters) per day. Only one major lost circulation zone was encountered in the core hole. This occurred at 2111 feet (643 m) where a vertical fracture was intersected and the water level dropped to 225 feet (69 m) bs.

Geophysical Borehole Logging

Two logging runs were conducted in CTGH-1. The first was at a drilled depth of 517 feet (158 m) prior to setting the surface casing. The second occurred at the total depth of 4800 feet (1463 m). Copies of these logs are available through Rocky Mountain Well Logging Service. The pertinent aspects of each run follows.

Shallow Logging Run

Temperature, fluid resistivity, spontaneous potential, 16-64" resistivity, natural gamma, gamma-gamma density, guard resistivity and deviation logs were run from about surface to 517 feet (158 m), Table 1. Static water level was measured at 18 feet (6 m) bs. A fresh water zone was detected at 130 feet (40 m) and the formation(s) from surface to 517 feet (158 m) were found to be highly resistive. Appendix 3 contains the drill site geologists' report in this operation. The report prepared by COLOG, Inc. is given in Appendix 4.

Deep Logging Run

Temperature, fluid resistivity, spontaneous potential, 16-64" resistivity, induced polarization, 6' lateral, natural gamma, neutron density, caliper and sonic logs were run at varying intervals from surface to 4799 feet (1463 m). Table 1 presents the depth intervals covered by these various logs. The presence of HX rods from surface to about 4200 feet (1280 m) and/or high bottomhole temperatures relative to the thermal rating of the geophysical logging equipment utilized, prohibited acquisition of a complete suite of logs for this hole.

The temperature rating for the most of the geophysical tools is 150°F (66°C). It was anticipated that the borehole could be sufficiently cooled by the pumping of cold water to successfully employ these low temperature tools. Two separate cooling periods, each ranging from eight to ten hours in duration, were conducted in an attempt to cool the deep borehole. Approximately 6,000 and 11,000 gallons (22,713 and 41,640 liters) were pumped into the hole, respectively. Static water level was measured at about 20 feet (6 m) for both periods. During the first cooling period, maximum bottomhole temperature was reduced from 204 to 153°F (96 to 67°C) . However, full thermal recovery was achieved within ten hours after cooling efforts ceased in both cases. The small hole diameter (less than 3") and limited permeability precluded any significant cooling.

A detailed report on the deep geophysical logging operation prepared by COLOG, Inc. is given in Appendix 5. The open hole from 4205 to 4800 feet (1282 to 1463 m), can be characterized as having low-resistivity (4 to 10 ohm-meters) with localized zones of high-resistivity (25 to 75 ohm-meters) and high neutron counts suggesting very little hydrogen content (i.e., water and/or clay alteration). The low-resistivity zones correspond to intervals of higher porosity, as indicated by the slower sonic delta transit times. COLOG's report states on this basis that the hole has low porosity, little permeability and is dry. An apparent discrepancy exists in that the very low-resistivity indicated in the hole is enigmatic given the low hydrogen content indicated. UURI is currently investigating this problem.

POST-COMPLETION TEMPERATURE SURVEY

Under contract to DOE, Dr. D. Blackwell, of Southern Methodist University, conducted temperature surveys in CTGH-1 on 27 September 1986 and 6 August 1987 as part of DOE's data collection activity (Blackwell, 1986 and 1987). The results of the two surveys conducted, almost one year apart, are essentially identical. The first survey performed 20 days after hole completion is presented in Figure 11. An isothermal region is evident from 75 to 725 feet (23 to 221 m) underlain by an increasing conductive gradient as shown below.

DEPTH INTERVAL (ft)	THERMAL GRADIENT (°F/100 ft)
725-1200	1.54
1200-1675	3.31
1675-4800	4.5

The maximum bottomhole temperature is 206°F (97°C) at 4800 feet (1463 m). The thermal gradient from 1675 feet to total depth is believed to reflect the undisturbed conductive regime of the area. The isothermal zone from 75 to 725 feet (23 to 221 m) is interpreted as a zone of active through flowing cold groundwater. The intervening interval represents a transition zone between these two thermal-hydrologic regimes. The so-called "rain curtain" effect considered operative in the High Cascades extends to a depth of about 1700 feet (518 m)and is most prominent in the 75 to 1200 foot (23 to 366 m) depth interval in the CTGH-1 area.

Blackwell's temperature data correlates well with the survey run nine days after the coring operation was shutdown by the U. S. Forest Service (see **DRILLING/CORING AND COMPLETION** section). This agreement indicates that the hole thermally re-equilibrated rapidly which is consistent with the observations made during the geophysical logging operation (see previous section).

COST OF OPERATION

Total cost of CTGH-1 was $456,506. This expenditure encompasses the entire operation including site preparation, drilling and coring, mud logging, geophysical borehole logging and all other miscellaneous related items (Table 2). Average cost for CTGH-1 was $95 per foot. Not included in the total expenditure was the value for 4200 feet (1280 m) of HX rods left in the hole and Thermal Power Company staff time.

DISCUSSION

The 4800-foot (1463 m) CTGH-1 tested the basis of the Clackamas exploration model (Figure 2 and 4). The formations penetrated by the hole show evidence of tectonic fracturing and brecciation supporting the postulation of faulting in the area. Low-resistivity in the 4200 to 4800 foot (1280 to 1463 m) interval indicated by the geophysical borehole resistivity logs validates the interpreted areal low-resistivity anomaly as detected by the telluric magneto telluric survey (Figure 2) and the one-dimensional Bostick inversion for the drill site (Figure 5).

The stabilized temperature profile demonstrates that the "rain curtain" effect extends to about 1700 feet (518 m). Below this depth, a constant 4.5°F/100 feet (82°C/km) temperature gradient is observed to 4800 feet (1463 m). The maximum bottomhole temperature is 206°F (97°C) at total depth. These data suggest that valid temperature gradients can be obtained by holes nominally 2500 feet (762 m) in depth in this area (Priest and Woller, 1987). The Breitenbush Formation which hosts the shallow aquifer in the deep well at Breitenbush Hot Springs (Priest, 1987) lies below the total depth of CTGH-1 perhaps at about 7000 feet (2134 m), according to Dr. G. Priest (oral commun., 1987).

The geophysical borehole logs indicate the bottom portion of the hole to be of limited permeability and to be essentially dry. This is consistent with the observed rapid thermal re-equilibration after cooling the hole and with the conductive thermal regime. Secondary alteration mineralogy does not evidence the presence of an active or a paleo, high-temperature hydrothermal system. Therefore, the low-resistivity anomaly detected by the telluric-magnetotelluric survey and indicated by the borehole resistivity logs is clearly of non-thermal origin. Clay alteration has been proposed as a possible mechanism to generate the electric anomaly (P.M. Wright, oral commun., 1986). He reports a comparable phenomenon for the GEO Operator thermal hole, N-1, in the Newberry Volcano area which was also drilled/cored under the DOE Cascade Geothermal Drilling Project. It is important to note, however, that the drill site lithologic description and the borehole neutron density logs do not indicate a significant amount of clay alteration. The data suggests that only minor amounts of clay alteration are required to cause the observed low-resistivity anomaly.

Blackwell and Steele (in press) determined that the heat flow in CTGH-1 is 115mWm^{-2} which supports the earlier hypothesis of Blackwell et al. (1982) that the axis of the High Cascades in Oregon should be associated with a high heat flow. Downward extrapolation of the 4.5°F/100 feet (82°C/km) temperature gradient suggests that at depth greater than 9000 feet (2743 m), temperatures of 400°F (205°C) are present. The potential for a commercial-grade hydrothermal system in the Clackamas prospect is therefore indicated.

DOE RESEARCH

The DOE has funded a detailed scientific study on CTGH-1 by the Southern Methodist University, UURI and DOGAMI. Dr. David Blackwell of Southern Methodist University, as previously described, has been collecting temperature and heat flow data. Well log analysis will be done by the UURI.

It is expected that they will document the relationship between clay alteration and the borehole geophysical logs. DOGAMI will (1) conduct a detailed study of the volcanic stratigraphy of the hole, and (2) stratigraphically correlate the 4800 feet (1463 m) hole to other shallower holes in the region and the deep Breitenbush well. In addition to the DOE activities, the U.S. Geological Survey also will perform other scientific studies in the area. Bargar (1987) recently completed a secondary alternative minerology study of CTGH-1, as discussed above. Dr. D. Sherrod and Mr. R. Conrey are doing geologic field mapping in the region. It is anticipated that DOGAMI will synthesize all available scientific data to develop a model of the geothermal system in the Brietenbush Olallie Butte region (Priest and Woller, 1987). This synthesis is expected to be released as a DOGAMI open-file report.

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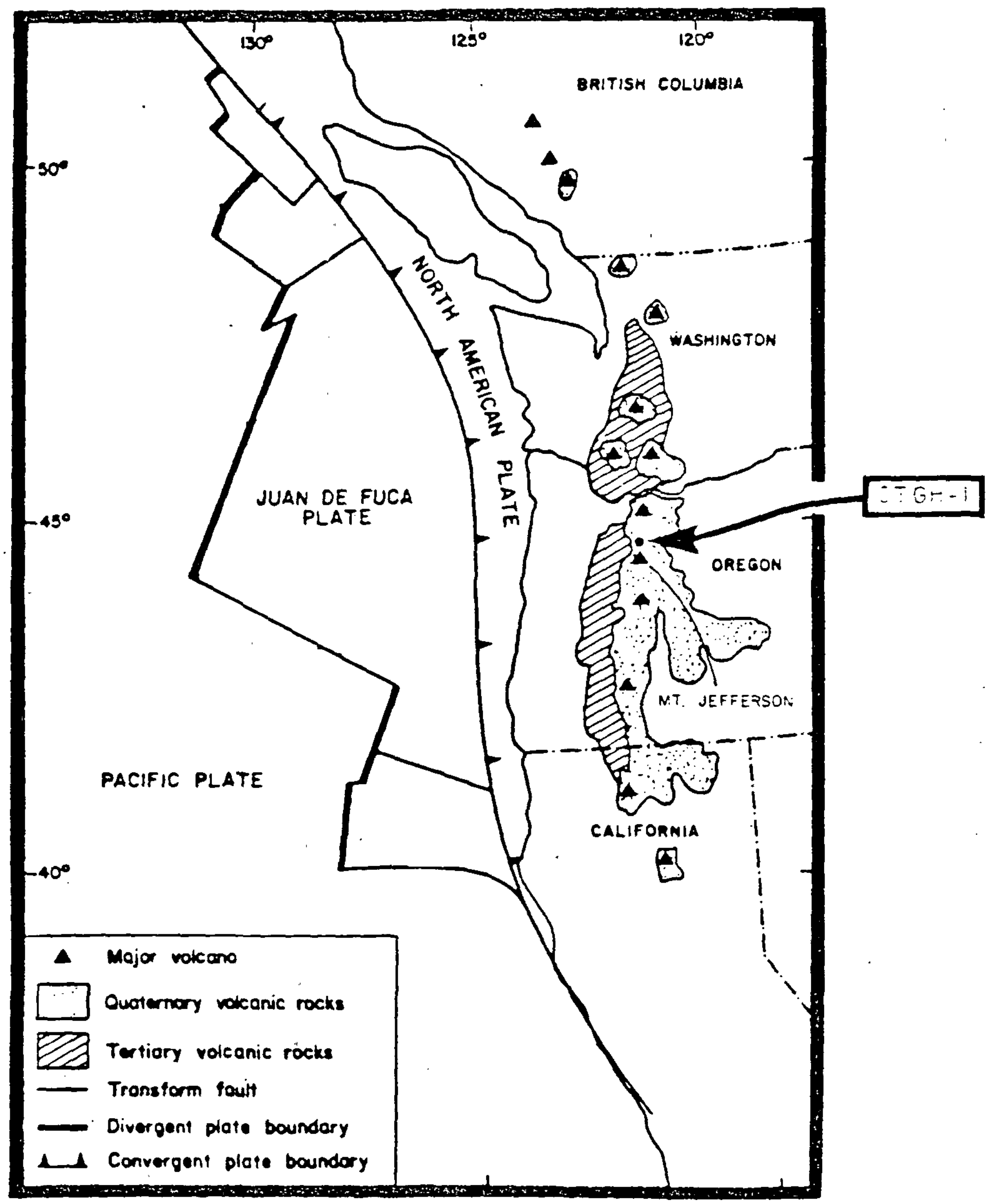


Figure 1. Location map for the Clackamas geothermal prospect (modified after Priest, 1987)

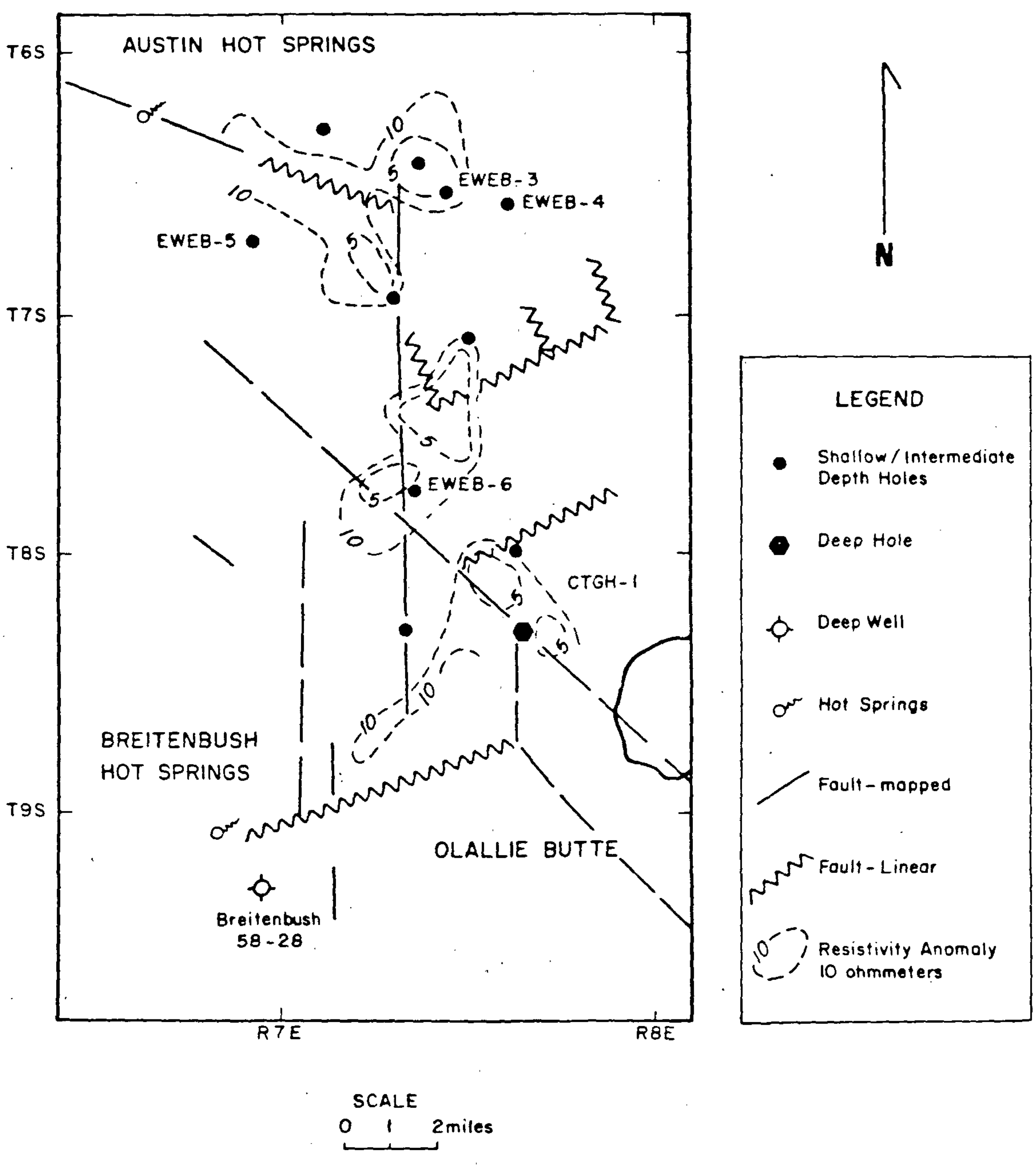


Figure 2. Principal elements of the Clackamas geothermal prospect.

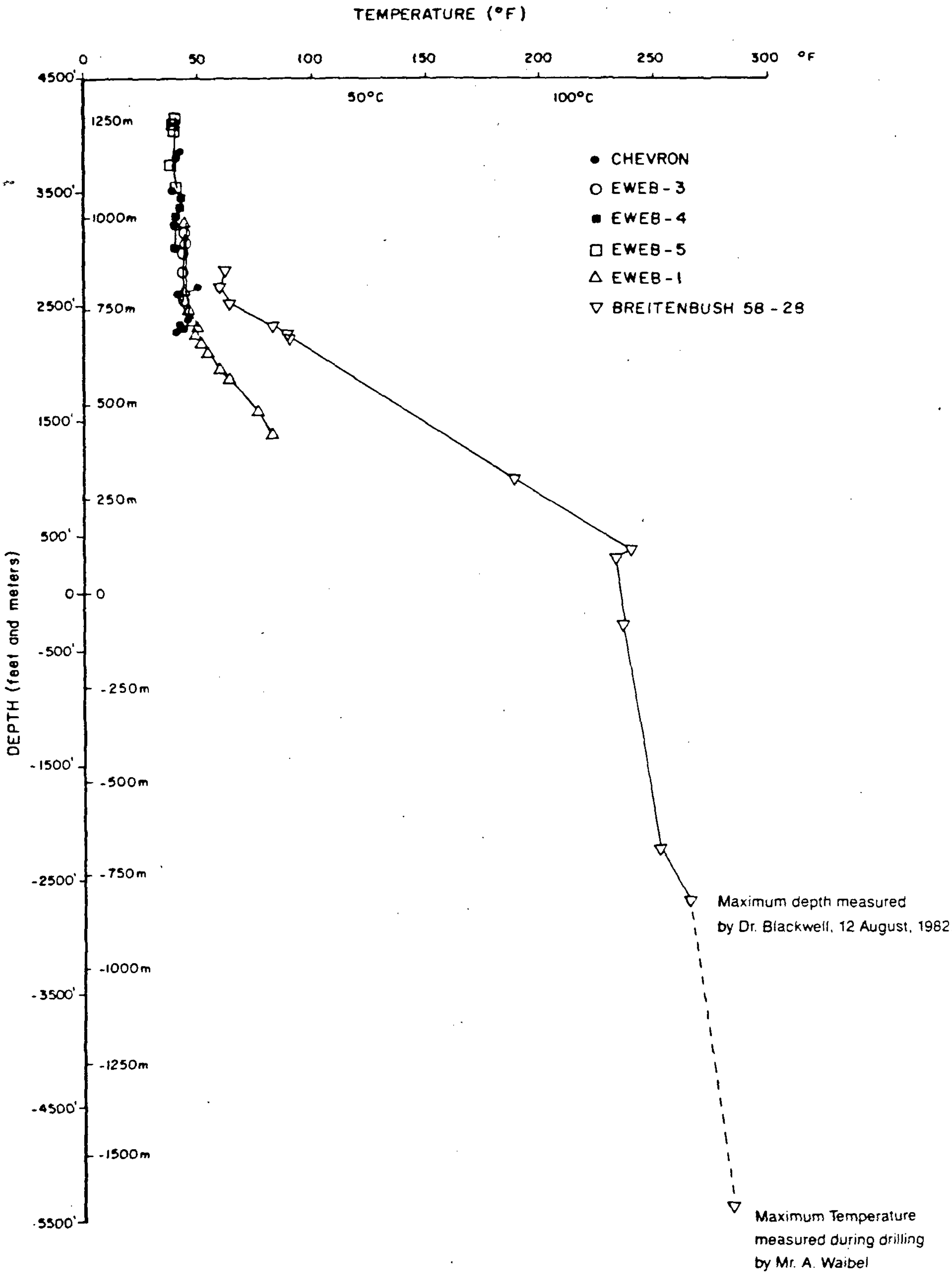


Figure 3. Temperature-depth plot of Clackamas area shallow and intermediate depth holes and the Breitenbush 58-28 well.

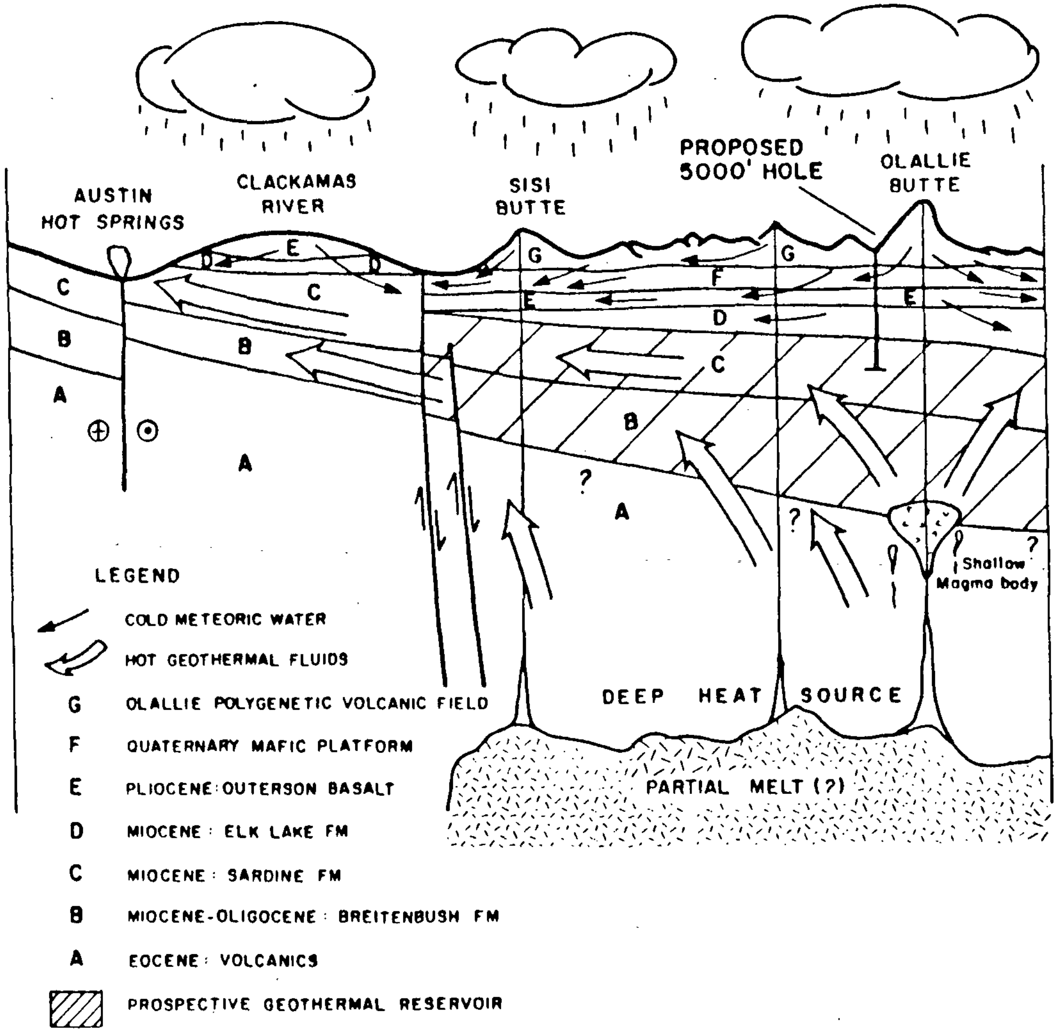


Figure 4. Pre-drilling model for the Clackamas geothermal system.

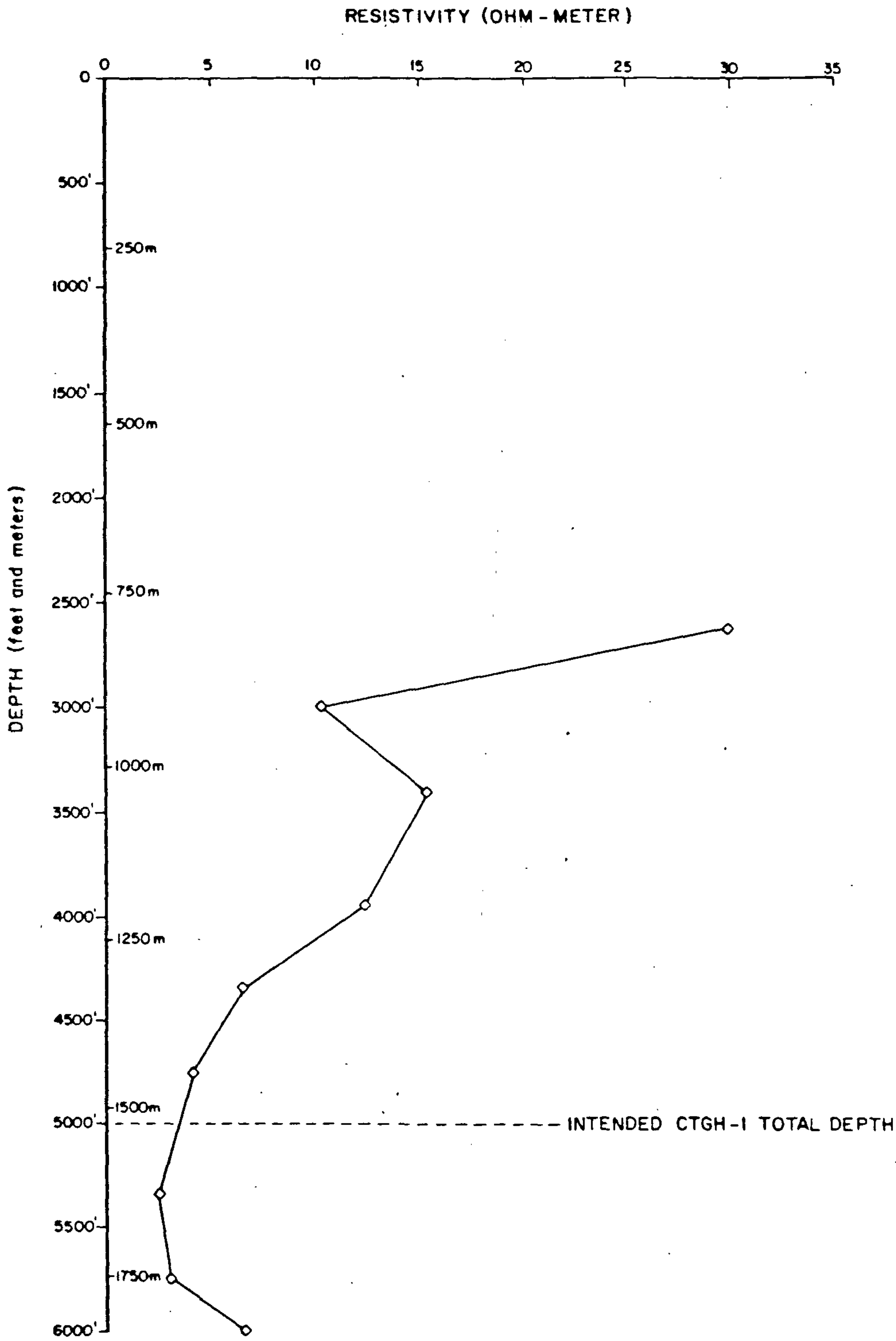


Figure 5. One-dimensional Bostick inversion of a telluric-magnetotelluric station near the CTGH-1 site.

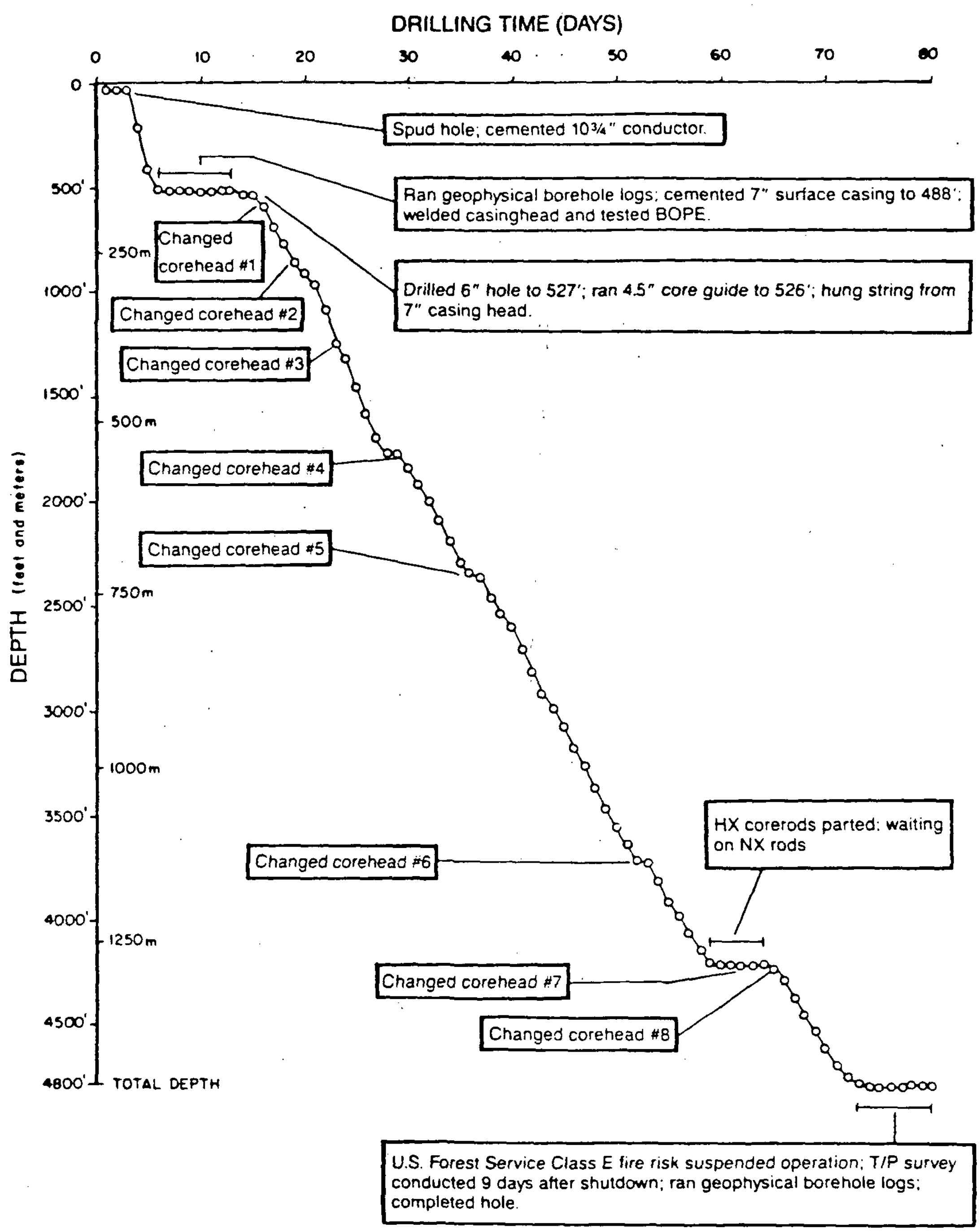


Figure 6. Depth penetration profile for CTGH-1.

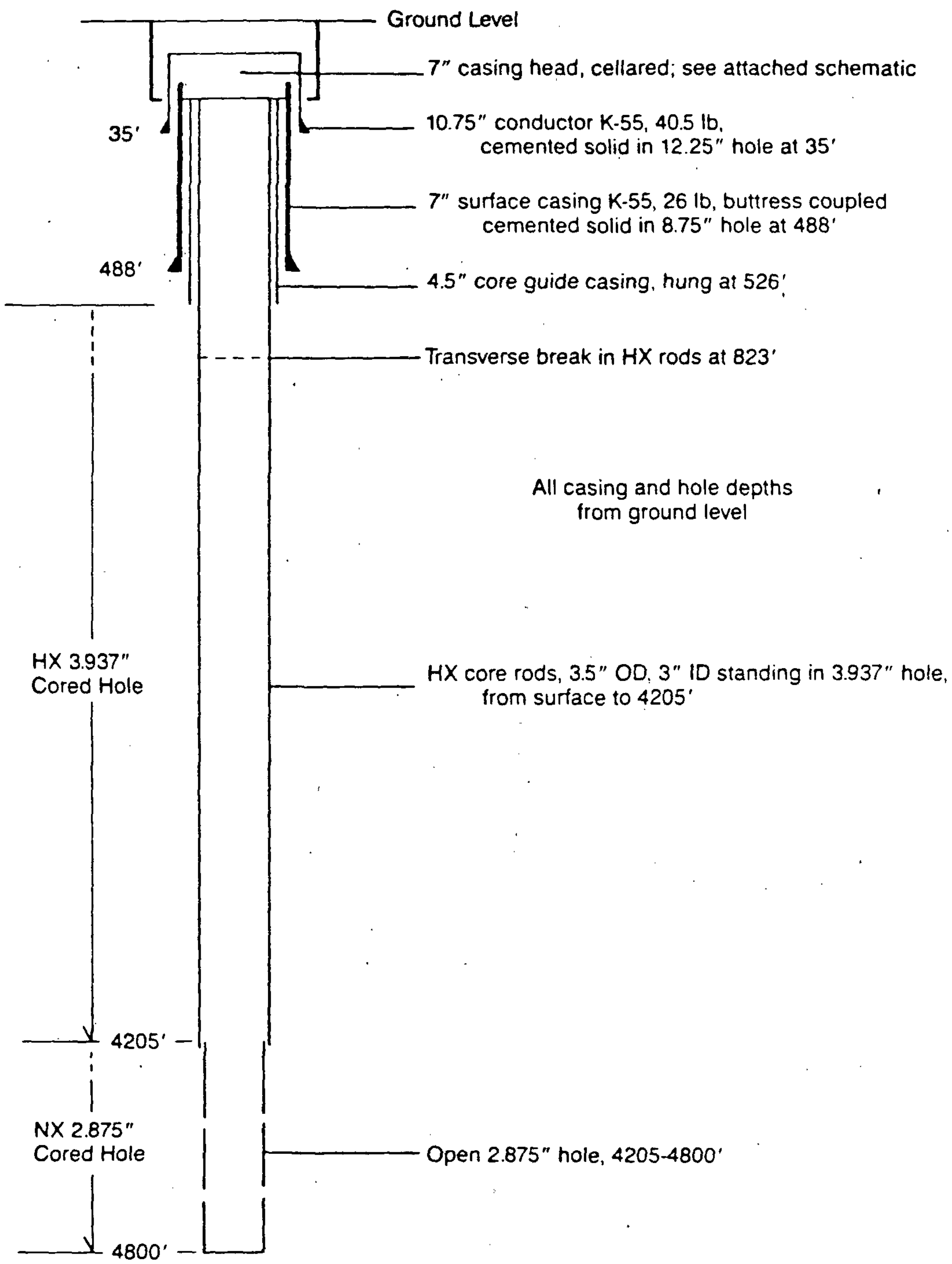
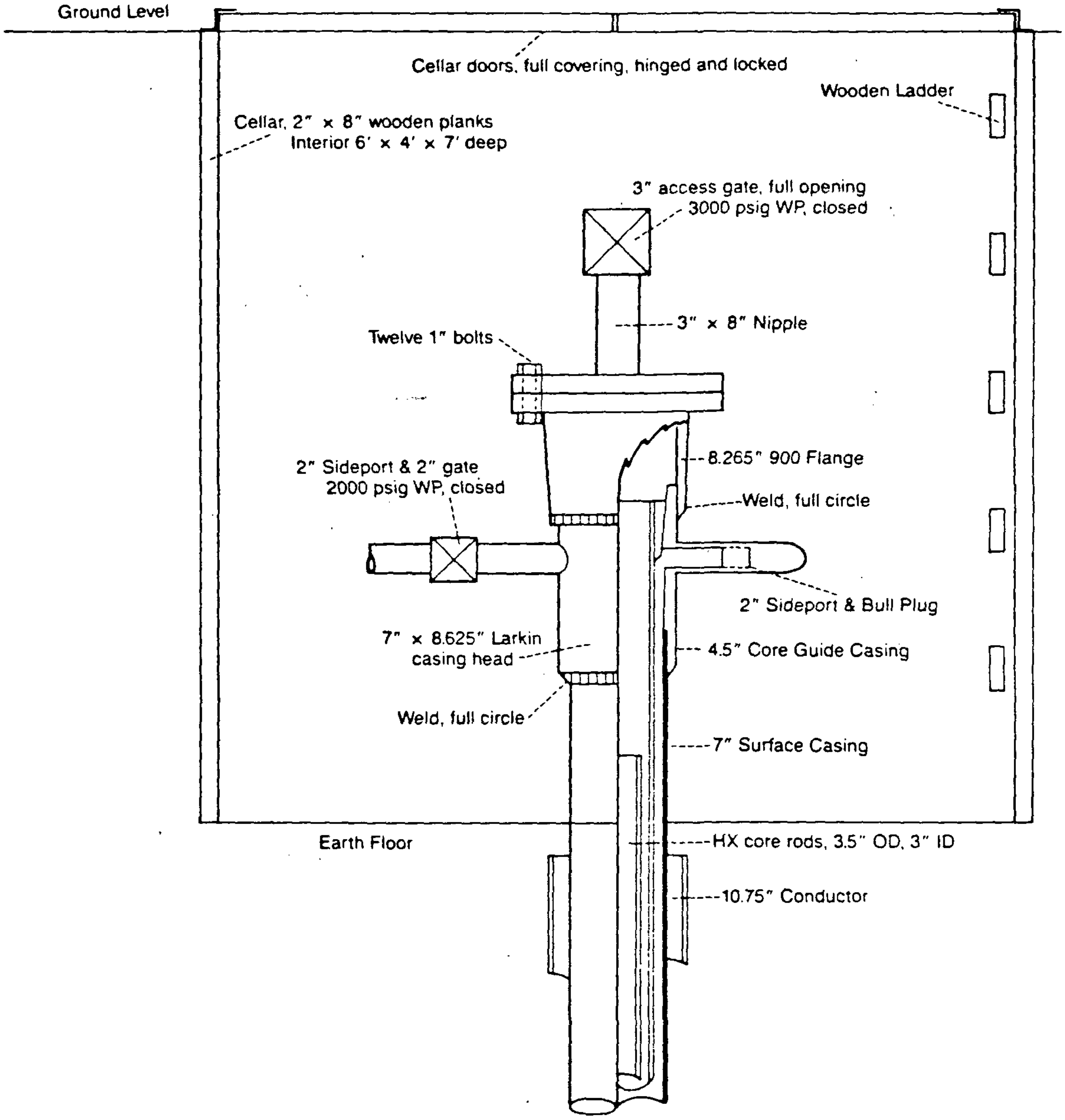


Figure 7. CTGH-1 subsurface completion configuration schematic.



Keys to Cellar Lock With:

TPC, San Francisco, Calif. 415/765-0306

Figure 8. CTGH-1 casing head, access gate and cellar schematic.

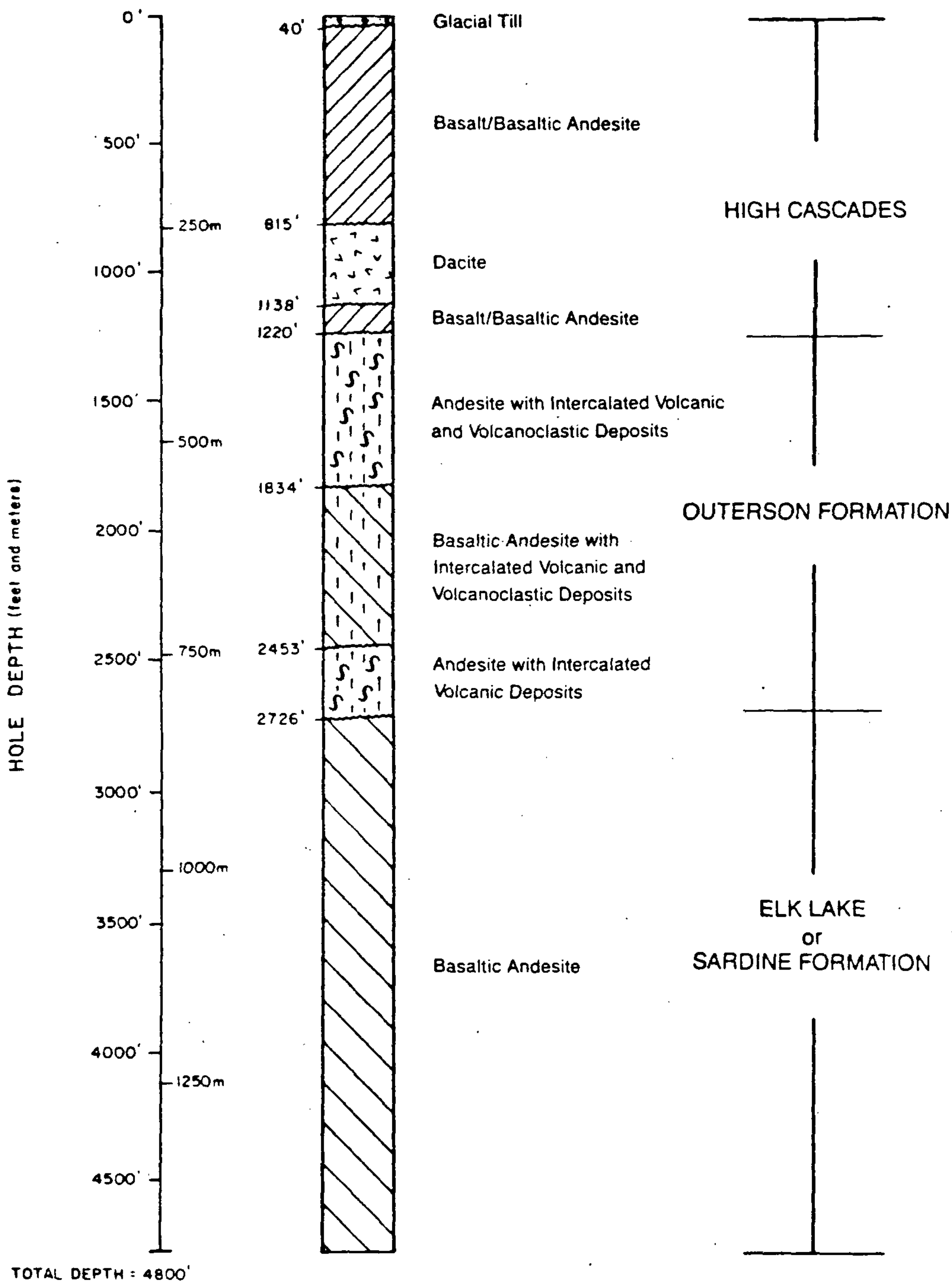


Figure 9. Generalized lithologic column for CTGH-1.

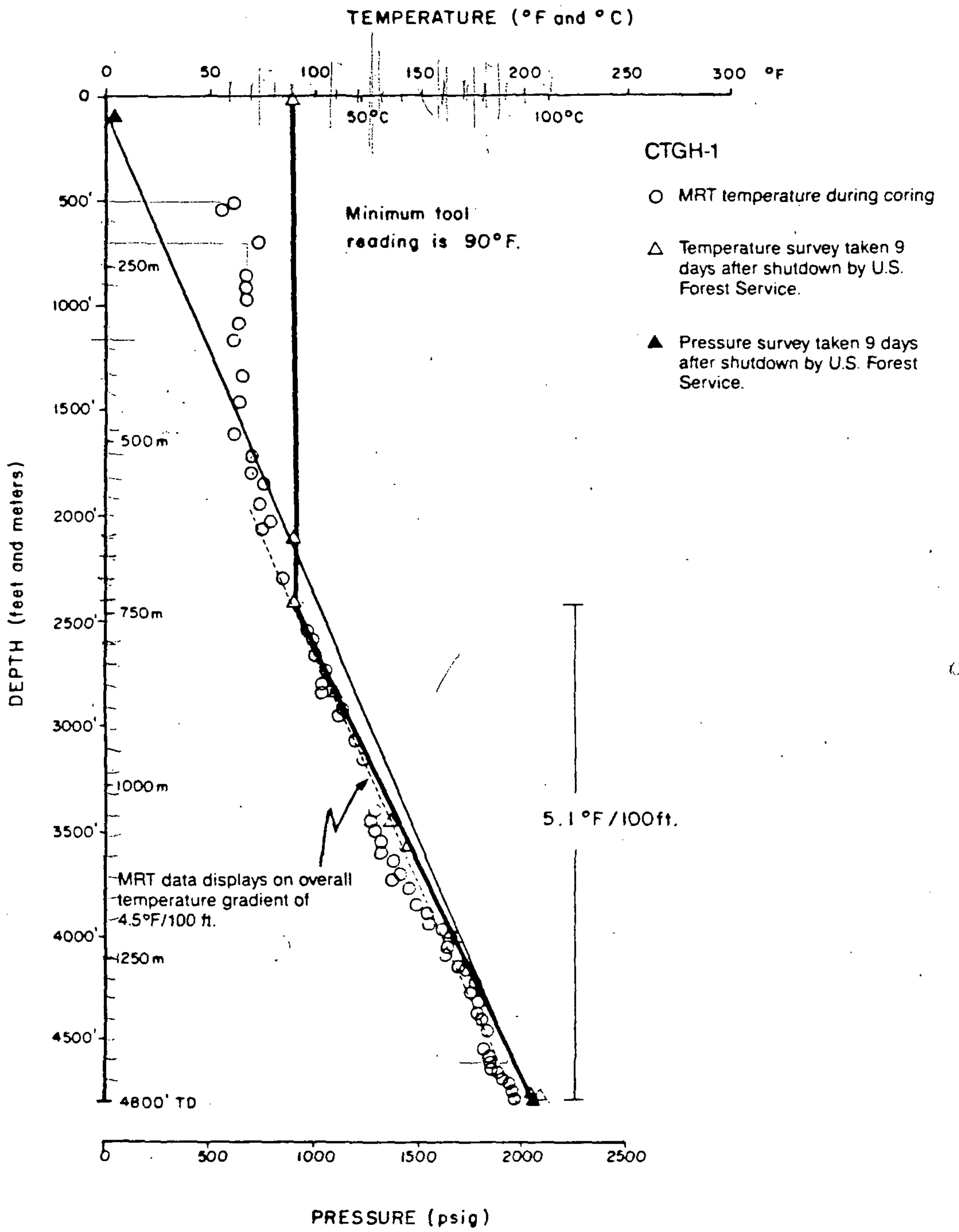


Figure 10. Temperature and pressure-depth plot for CTGH-1. Also shown are the maximum recording thermometer (MRT) temperatures obtained while coring.

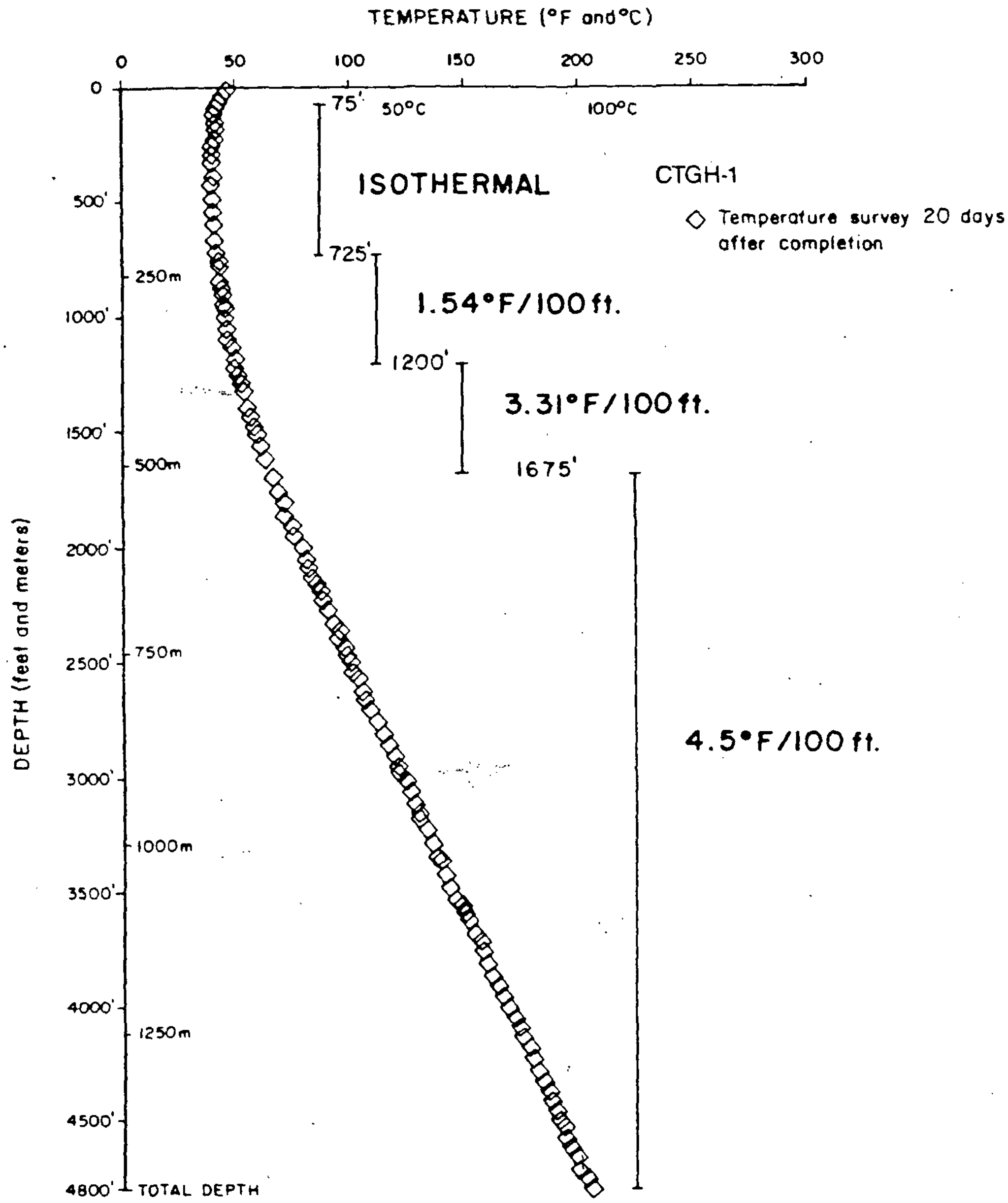


Figure 11. Temperature-depth plot for CTGH-1 as determined by Blackwell (1986).

Table 1. CTGH-1 geophysical borehole logs

	LOG TYPE	INTERVAL LOGGED (ft)
SHALLOW LOGGING RUN	Temperature	0-517
	Fluid Resistivity	
	Spontaneous Potential	35-516
	16-64" Resistivity	
	Natural Gamma	0-510
	Gamma-Gamma Density*	0-516
	Guard Resistivity	20-514
	Caliper	0-510
	Deviation	0-516
DEEP LOGGING RUN	Temperature	0-4785
	Fluid Resistivity	
	Spontaneous Potential	4200-4798
	16-64" Resistivity	4200-4799
	Induced Polarization	
	6' Lateral (Resistivity)	4200-4748
	Natural Gamma	0-4800
	Neutron Density*	
	Caliper	775-4745
	Gamma-Gamma Density	775-900
	Sonic (Δt)	4225-4425
	Inclination	75-4805

*Both uncompensated and compensated logs are available from Rocky Mountain Well Logging Service.

Table 2. Itemization of CTGH-1 Expenditure.

Item	Total Cost ($)
Road, site and location	11,544.39
Rig Mob./Demob.	10,000.00
Rig	296,807.04
Trucking & hauling	3,889.84
Drill site geologists	26,560.00
Mud & chemicals	24,618.32
Cement materials	9,140.65
Geophysical logging	10,031.91
Drill bits & tools	23,492.83
Outside labor	1,423.85
Other evaluation	6,954.20
Other	14,125.20
Conductor casing	418.80
Surface casing	10,588.64
Wellhead equipment	2,589.46
Camp & catering	4,270.89
TOTAL	$456,506.02

Appendix 1. Drilling and completion history for CTGH-1. The U. S. Bureau of Land Management and Oregon Department of Geologic and Mineral Industries Completion Reports are also provided.

THERMAL POWER COMPANY
Santa Rosa Office

Clackamas Thermal Gradient Hole CTGH-1

DRILLING AND COMPLETION HISTORY

DATE	ACTIVITY
7 June 1986	Spudded 1030 hours with Boyles Bros. rotary rig. Drilled 12-1/4" hole to 35' but could not run a 10-3/4" conductor below 12'.
8 June 1986	Moved rig 6' and drilled a 8-3/4" hole to 35'; opened hole to 12-1/4". Ran 10-3/4", 40.5 lbs K-55 conductor to 28'.
9 June 1986	Completed running conductor to 35'. Cemented conductor with 16 sacks Portland cement, 16 sacks construction cement and 3% $CaCl_2$. Cement in place at 1430 hours. Waiting on cement.
10-12 June 1986	Drilled 8-3/4" hole from 35 - 517'. Lost 50% (+1000 gals) of drilling mud at 400 - 410' and 60 barrels at 425'.
13 June 1986	Geophysical borehole logging conducted. Circulated hole clean in preparation for running 7", 26 lbs K-55 buttress casing. Ran casing which became stuck at 488'; unable to circulate casing to bottom or pull up. Rigged up Halliburton cementers. Pumped 5 barrels of water ahead of 13.5 pound per gallon slurry of 122 cubic feet of Class G cement, mixed 1:1 with perlit plus 40% silica flour and 2% gel. Followed with 15.5 pound per gallon tail slurry of 32 cubic feet of Class G cement plus 40% silica flour. Displaced slurries with 19 barrels of water. Obtained good cement returns at surface. Plug bumped at 4000 psig and held. Cement level dropped in 7" to 10-3/4" annulus. Cement operation witnessed and approved by BLM.
14 June 1986	Outside cement job completed with four barrels of Class G cement mixed 1:1 with perlite; filled 7" to 10-3/4" annulus to surface. Released rotary rig. Dug cellar.
15 June 1986	Completed cellar construction. Welded LARKIN casing head to 7" casing. Set up BOPE and notified BLM and DOGAMI for BOP test.

16 June 1986	Leak in 8-5/8" x 6" Series 900 flange in 7" Larkin casing head precluded successful BOPE test. Waiting on air delivery of replacement flange.
17 June 1986	Reworked threads on 8-5/8" x 6" 900-series flange but would not seat properly. Air delivered flange seated and sealed in Larkin head. Rigged BOPE including Hydril MSP 2000 unit. Shaffer dougle gate with blind and rod rams, remote hydraulic controls.
18 June 1986	BOPE tested and approved by BLM.
19 June 1986	Stabilized Boyles Bros. core rig over BOPE and cellar; built rig floor.
20 June 1986	Drilled float collar at 466' and cement to 488' with 6" bit. Cleaned out hole to 517' and drilled to 527'. Circulated 30 minutes and pulled out of hole (POH). Left fish (6" bit and 4.5' joint) on bottom. Called for an overshot.
21 June 1986	Recovered fish. Ran 4.5" core guide string to 526' and hung string from 7" casing head.
22-24 June 1986	Cored ahead with 3.937" diamond corehead (HX size) from 527 - 744' with full core recovery. Lost total fluid return at 530' (22 June). Attempted to plug LCZ from shoe of 7" (488') with LCM and mud on 24 June with no success.
25-30 June 1986	Cored from 854' to 1316' with no fluid returns. Tripped out of hole for new HX bit at 1271'. Experienced mud thinning due to water inflow on 25 June; greased rods on 27th. Core recovery virtually 100%.
1-5 July 1986	Cored from 1316' to 1775' with no fluid returns where tripped for new bit. Core recovery 100%.
6-12 July 1986	Cored from 1775' to 2336' with no fluid returns and 100% core recovery. Wireline broke pulling core at 2336'; POH for repair and new bit. H_2S detection equipment installed and operating on 8 July. All three crews trained in H_2S safety and equipment. Electronic failure of H_2S detection equipment on 9 July (2083'). Repaired and operating by 2500'. Maximum recording thermometer temperatures (MRT) at 2130' and 2243' were 75° and 69°F respectively.
13-14 July 1986	Cored from 2366' to 2466' with no fluid returns and 100% core recovery.

15 July 1986	Cored to 2476'. Core barrel jammed in core rods at ±500' depth upon core retrieval. Wireline broke, POH 17 stands and retrieved core barrel. Laid down one joint of bad core rod. Ran in hole (RIH) and washed bridge from 1776' to 1780' and 5' of fill on bottom. Cored to 2535' with no fluid returns and 100% core recovery. MRT at 2544' was 96°F.
16 July 1986	Cored to 2594' with no fluid returns and 100% core recovery. Upon core retrieval at 2584', barrel became stuck at 400' and wireline broke. POH; laid down one bad joint of core rod. MRT at 2584' was 99°F.
17-28 July 1986	Cored from 2594' to 3721' with no fluid returns and 100% core recovery. POH to change bit after 1385' and 340 hours; only one-third worn. MRT data as follows: 3059' = 119°F; 3159' = 124°F; 3254' = 131°F; 3641' = 138°F and 3711' = 137°F.
29 July- August 1986	Cored from 3721' to 4203' with no fluid returns and 100% core recovery. HX core rods parted while coring at 4203'. Waiting on NX rods to run fishing spear.
5-7 August, 1986	Waiting on NX rods. RIH with NX open ended and found HX rods parted at 823'. RIH to retrieve core barrel at 4193'.
8-10 August 1986	Recovered core barrel after two attempts. RIH with 2.875" diamond corehead (NX size) and NCC rods. Milled out HX bit at 4203' and cored ahead to 4226'. POH to replace bit. MRT at 4216' was 177°F.
11-17 August 1986	Cored from 4226' to 4780' with no fluid returns and 100% core recovery. Received a U. S. Forest Service order for complete shutdown of rig operations because of a Class E fire risk. MRT data as follows: 4296' = 178°F; 4383' = 183°F; and 4540' - 182°F.
18 August 1986	Cored from 4780' to 4800' with no fluid returns and 100% core recovery. Could not obtain exception to shutdown order in spite of about 900 barrels water supply on the drillsite which is located in a clear-cut. POH to 4150'. Closed blind rams and Hydril on NCC rods; closed Kelly valve and shutdown operations at 1200 hrs.
27 August 1986	Ran a Pruett wireline temperature/pressure survey after nine-day shutdown with U. S. Forest Service approval. Recorded maximum hole temperature of 210°F at total depth.

0 August 1986	Class E fire risk condition lifted. Drillsite operations scheduled to resume 2 September.
2 September 1986	Started operations at 2000 hours. Ran NCC rods and NX bit string from 4250' to 4800'. Hole clear to bottom. Initiated hole cooling for geophysical logging operation. MRT at 4800' is 204°F.
3 September 1986	Cooled borehole with 8 hour circulation to about 153°F. NCC rods POH.
4 September 1986	Ran gamma-gamma density/caliper, sonic and spontaneous potential/16'-64' resistivity logs. Temperature in hole rebounded quickly, to over 185°F which caused the density and sonic tools to fail. Found erratic readings from resistivity tool; cablehead problem. POH, ran NCC rods into hole to initiate cooling again.
5-7 September 1986	Completed borehole geophysical logging. Laid down NCC rods, pumped out cellar and removed BOPE. Bolted 1-1/4" plate flange to LARKIN casing head. Flange includes a 3" full opening gate to allow logging tool access. Rigged down, cleaned cellar and pits. Released rig on 1300 hours, 7 September 1986.

Diamond Shamrock
Thermal Power Company

29 October 1986

Mr. Patrick Geehan
Deputy State Director for Mineral Resources
Bureau of Land Management
U. S. Department of the Interior
P. O. Box 2965
Portland, Oregon 97208

Re: Clackamas Thermal Gradient Hole CTGH-1
Federal Geothermal Lease OR 12344
Marion County, Oregon

Dear Mr. Geehan:

Drilling operations for CTGH-1 commenced 7 June 1986 and completed on 7 September 1986 as an activity of the DOE Cascades Thermal Gradient Drilling Project. We submit herewith Geothermal Well Completion Report, Drilling and Completion History, schematics showing actual completion configuration and casing head, access gate and cellar. Complete copies of all core, lithology, geophysical logs and temperature surveys are also submitted under this letter. Complete duplicate information is being provided today to the Oregon Department of Geology and Mineral Industries.

Please be aware that the 4800-foot CTGH-1 is being retained in a shut-in mode during the 12-month DOE Access Period which commenced 7 September 1986. No abandonment procedure is enclosed because Thermal is evaluating options for additional borehole evaluation activity in 1987, possible borehole deepening or a suspended retention as allowed under the lease provisions.

Very truly yours,

W. L. D'Olier
Vice President
Geothermal Exploration

WLD/ma

cc Susan Prestwich, DOE Idaho Falls

Thermal Power Company
A subsidiary of Diamond Shamrock, 3333 Mendocino Avenue, Suite 120, Santa Rosa, California 95401
Phone 707 576-7022

INSTRUCTIONS

GENERAL: This form is designed for submitting a complete and accurate geothermal well completion report, and should be accompanied by a detailed chronological history of well operations and final copies of the results of any logs, surveys or tests performed on the well, which have not previously been submitted. The report shall be submitted within 30 days after the date of completion of continuous well activities, as determined by the District Geothermal Supervisor. The completion date in many cases will be the day the drilling rig is released. The Supervisor may postpone the required report submittal date if adequate justification is presented by the lessee.

ITEM 18: Show the surface location coordinates from the nearest section corner or tract line. Show production zone and total depth coordinates from the surface location if the well is directionally drilled.

ITEM 34: If the well is immediately placed into operation without testing, this section should reflect the first month's production data.

ITEMS 35 & 36: Indicate the depth(s) of subsurface pressure and temperature measurement, and include the reference datum.

Temperature/Pressure Survey: 0-4800'

33. WELL TEST

TEST DATE	PRODUCTION METHOD: FLOWING ( ) OTHER ( ) PUMPING ( ) - include size, type, intake depth, etc.
N/A	

34. PRODUCTION

HOURS TESTED	PRODUCTION DURING TEST			ENTHALPY (Btu/lb)
	TOTAL LIQUIDS (lb)	STEAM (lb)	WATER (lb)	

35. STATIC TEST DATA

DEPTH	SURFACE PRESSURE (psig)	SUBSURFACE PRESSURE (psig)	SUBSURFACE TEMPERATURE (°F)	WATER ANALYSIS	
				Total Dissolved Solids	pH

36. FLOWING TEST DATA

SURFACE PRESSURE	SUBSURFACE PRESSURE at ______ feet	SURFACE TEMPERATURE	SUBSURFACE TEMPERATURE at top of perfs.	AVE. TOTAL MASS FLOW RATE PER HOUR		
				TOTAL (lb/hr)	STEAM (lb/hr)	WATER (lb/hr)
WELLHEAD: SEPARATOR: N/A						

37. SUMMARY OF POROUS ZONES: Show all important porous zones and contents of each; cored intervals with recoveries, drill stem or formation tests with depth of interval tested, time open, cushion used, and flowing and shut-in pressures, temperatures and recoveries.

FORMATION	TOP	BOTTOM	DESCRIPTION OF DETAILS
			See Mud Log

38. GEOLOGIC MARKERS (TOP)

NAME	MEASURED DEPTH	TRUE VERTICAL DEPTH

Diamond Shamrock
Thermal Power Company

29 October 1986

Department of Geology and Mineral Industries
State of Oregon
910 State Office Building
Portland, Oregon 97201

Attention: Dennis L. Olmstead

Re: Clackamas Thermal Gradient Hole CTGH-1
Federal Geothermal Lease OR 12344
Marion County, Oregon

Gentlemen:

Drilling operations for CTGH-1 commenced 7 June 1986 and completed on 7 September 1986 as an activity of the DOE Cascades Thermal Gradient Drilling Project. We submit herewith Well Summary Report, Drilling and Completion History, schematics showing actual completion configuration and casing head, access gate and cellar. Complete copies of all core, lithology, geophysical logs and temperature surveys are also submitted under this letter.

Please be aware that the 4800-foot CTHG-1 is being retained in a shut-in mode during the 12-month DOE Access Period which commenced 7 September 1986. No abandonment procedure is enclosed because Thermal is considering options for additional borehole evaluation activity in 1987, possible borehole deepening or a suspended retention as allowed under the lease provisions.

Yours very truly,

W. L. D'Olier
Vice President
Geothermal Exploration

WLD/ma

cc Susan Prestwich, DOE Idaho Falls

Thermal Power Company
A subsidiary of Diamond Shamrock, 3333 Mendocino Avenue, Suite 120, Santa Rosa, California 95401
Phone 707 576-7022

Form 6-1/80

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1069 State Office Building Portland, Oregon 97201

WELL SUMMARY REPORT
(Geothermal Well)

Operator Thermal Power Company Field Squirrel Creek

Well No. CTGH-1* Sec. 28, T 8S, R 8E, WM W. B. & M.

Location 2200' N. and 1500' W of SE corner Sec 28 Elevation above sea level 3840 feet

All depth measurements taken from top of Rig floor, which is 4 feet above ground

In compliance with the rules and regulations pursuant to ORS 522 (Chapter 552 OL 1975) the information given herewith is a complete and correct record of the present condition of the well and all work done thereon, so far as can be determined from all available records.

Date 28 October 1986 Signed W. L. D'Olier

Title Vice President, Geothermal Exploration (President, Secretary or Agent)

Engineer or Geologist Superintendent

Commenced drilling 7 June 1986 Completed drilling 7 Sept. 1986 Drilling tools ~~xxxxx~~ Core 526-4800' Rotary 0-526'

Total depth 4800' Plugged depth N/A

GEOLOGICAL MARKERS	DEPTH
N/A	

Junk N/A

Commenced producing N/A Date

*Thermal Gradient Hole
DOE Cascades TG Drilling Project

	Water gpm	Temp °C	Total Dissolved Solids (ppm)	Steam lb/hr	Tubing Pressure	Casing Pressure
Initial production N/A						
Production after 30 days						

CASING RECORD (Present Hole)

Size of casing (A.P.L.)	Depth of shoe	Top of casing	Weight of casing	New or second hand	Seamless or lapweld	Grade of casing	Size of hole drilled	No. of sacks of cement	Depth of cementing if through perforations
10.75"	35'	0	40.5 lbs			K-55	12.25"	32	
7"	488'	0	26 lbs			K-55	8.75"	N/A	

PERFORATIONS

Size of casing	From	To	Size of perforations	Number of rows	Distance between centers	Method of perforations
	ft.	ft.				
	ft.	ft.				
	ft.	ft.				
	ft.	ft.				
	ft.					

Electrical Log Depths See Attachment 1 (Attach Copy of Log)

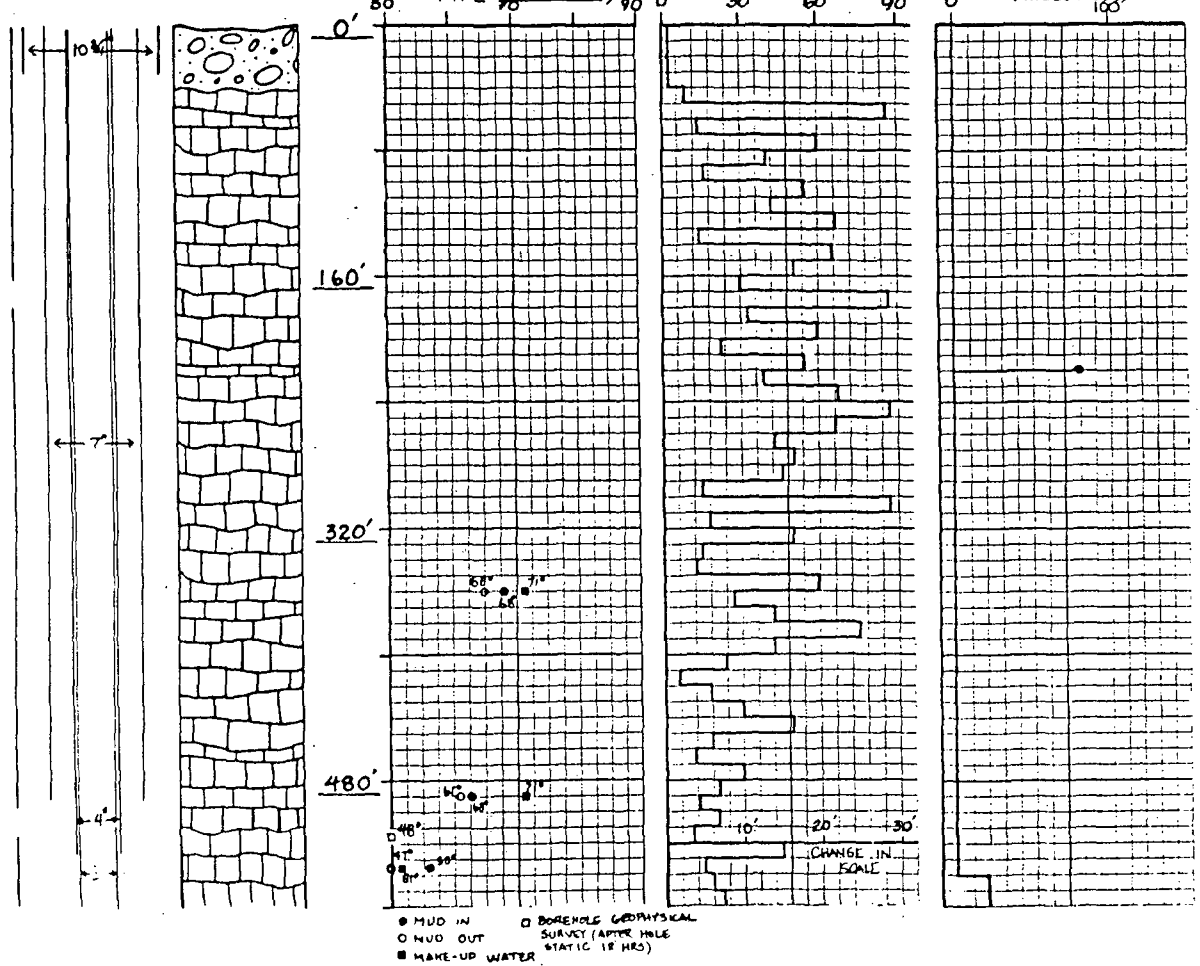
Appendix 2. CTGH-1 geologic log. The preliminary report on secondary mineralogy by Columbia Geoscience is also provided.

Diamond Shamrock
Thermal Power Company

FORM 4

HOLE	CTGH-1	SPUD DATE	6/7/86	COMPLETION DATE	7 Sept '86	TOTAL DEPTH	4800 feet
FIELD	CASCADE/CLACKAMAS	COUNTY	MARION	STATE	OREGON	TOTAL VERTICAL DEPTH	n/a
LOCATION	T8S, R8E, SEC. 28	ELEVATION	~3840'	☐ KB of ____ ☒ GL		BOTTOM HOLE LOCATION	—
CONTRACTOR / RIG	BOYLES BROS. / B82			GEOLOGIST (S)	GOODWIN, McDANNEL	DATE	

CASING PROFILE | LITHOLOGY | DEPTH | DRILLING TYPE | TEMPERATURE MRT (°F) | PENETRATION RATE | WATER LEVEL (Measured)



LOST CIRCULATION ZONES

220' - (rods in hole) Fluid level ~80' after 12 hours of no activity. ~300 gal returned level to zero. 6/11. 7:30

400' - Partial loss (~10%) ~100 gpm. 1000 gal. loss LCM brought full returns. 6/11. 16:00-17 00

425' - Total loss. 100 gpm. 3000 gal. loss. LCM brought full returns. 6/11. ~10.00 Decrease in mud viscosity suggests small H_2O entry @ 425'.

536' Partial loss. ~50% 18 gpm = 490 gal loss 5.10 am 6/22

540' Total loss @25 gpm 6 a.m. 6/22 Static water level ~20 below surface

LITHOLOGIC DESCRIPTION

0'-40': Qal. Basaltic boulders and cobbles (till)

40' : BASALT/BASALTIC ANDESITE LAVAS dk-med gry, minor red-brn. Aphyric to sparsely porph: phenos of plag, ol, pyx

Alteration: most of rock is fresh. Minor FeOx, clays; limonite, hematite 140'-150' tr. sulfide?

COMMENTS

ROTARY DRILLING

0'-35' 12¼" rock bit
10¾" casing

35'-517' 8¾" button bit (Smith F3)

150' inclination survey: ½° ∡

220' inclination survey: ½° ∡

527' completed rotary drilling. began coring

517' inclination survey. 2° ∡
set 7" casing 0-400'
borehole geophysical survey: resistivity, temperature, density, caliper, deviation, sp

BOP installed + tested.

Diamond Shamrock
Thermal Power Company

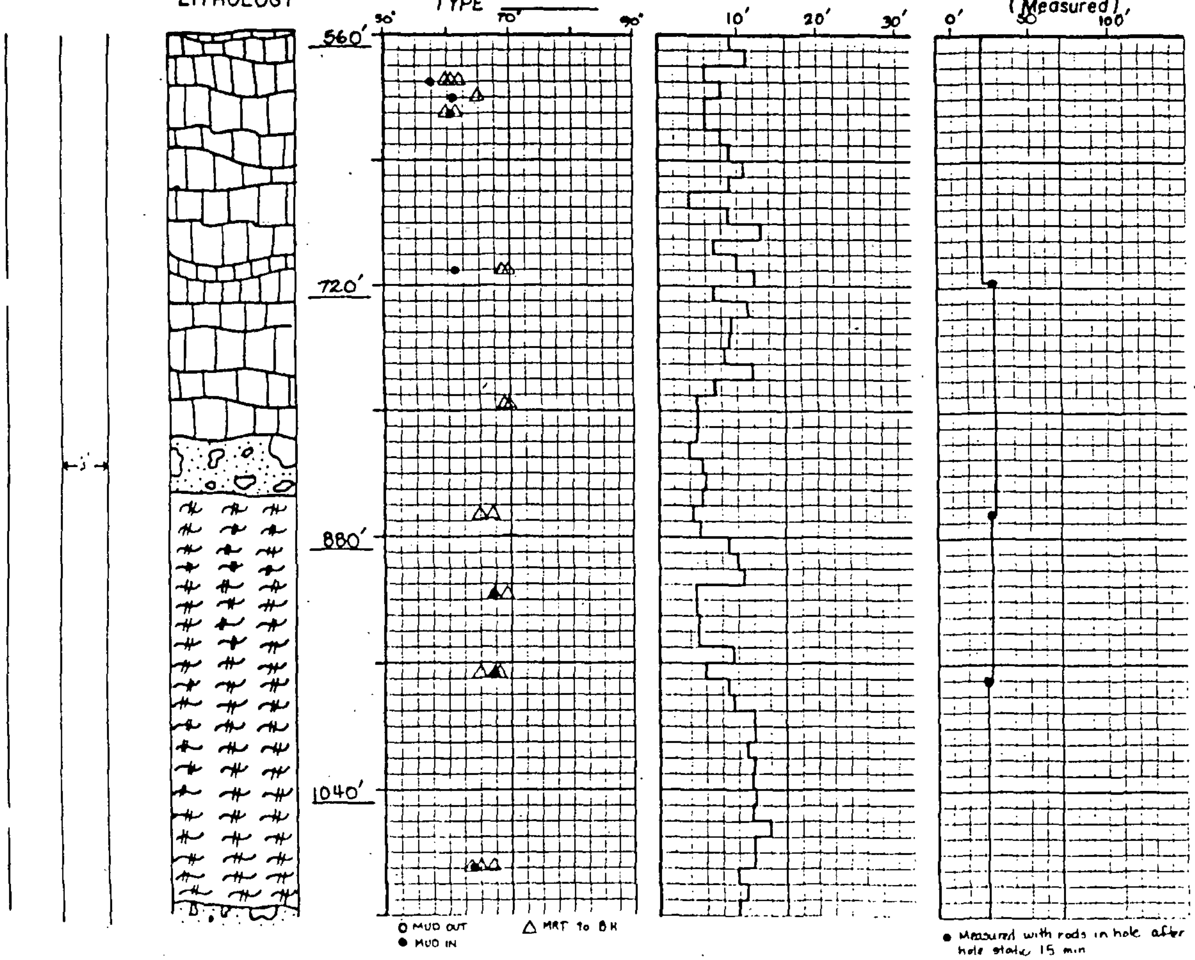
HOLE CTGH-1 | SPUD DATE 6/7/86 | COMPLETION DATE 7 Sept '86 | TOTAL DEPTH 4800 feet

FIELD CASCADES/CLACKAMAS | COUNTY MARION | STATE OREGON | TOTAL VERTICAL DEPTH n/a

LOCATION T8S, R8E, Sec. 28 | ELEVATION ~3840' | ☐ KB of ____ ☐ GL | BOTTOM HOLE LOCATION —

CONTRACTOR / RIG BOYLES BROS. / 882 | GEOLOGIST (S) GOODWIN / McDANNEL | DATE

CASING PROFILE | LITHOLOGY | DEPTH | DRILLING TYPE | TEMPERATURE | PENETRATION RATE | WATER LEVEL (Measured) | LOST CIRCULATION ZONES | LITHOLOGIC DESCRIPTION | COMMENTS



LOST CIRCULATION ZONES

Total loss continues. LCM added 549'-579'. Pump rate varies: 7-15 gpm. (400-1,000 gal/hr)

730' pulled up to 540' added LCM bomb. No returns.

LITHOLOGIC DESCRIPTION

BASALT / BASALTIC ANDESITE (as above) med lt gry - med gry finely porphyritic, ~10% phenos & glomerocrysts: plag, ol, pyx. White & pink clays coat frac. surfaces & vesicles. Zones of rubble, scoria, ash mark flow boundaries @ 579', 604', 683', 707', 771', 792'

809' VOLCANIC BRECCIA
Lapilli & blocks of basaltic to silicic rock fragments supported in a yellowish brn matrix of ash, crystals & ash sz rock fragments. Silicic fragments are more common near bottom of unit & appear to be from underlying dacite. Top 18 cm of unit is dk gry ash & ash sz rock fragments. Unit contains light to moderate amount of pink & brown clays, minor limonite stain.

854' DACITE Med lt gry fine gr., porphyritic. Phenos of plag, cpx, opx; groundmass of plag, pyx, black iron bearing mineral. Unit is intensely fractured. 76-80°, vertical. Clay on fracture surfaces (pink, brn), locally heavy pyrolusite, red FeOx, mnr plag → clay, tr. limonite, localized tr. chlorite.

1112' VOLCANIC BRECCIA
Lapilli & block sz mafic & silicic (less common) rock fragments in clayey matrix of ash sz rock fragments & crystals. Thin irregular beds & laminae of ash sz & lapilli fragments.

1138' - BASALT. med - med dk gry. 7-12% phenos: plag, cpx, olivine. Lt. orange & pinkish clay coat fracture surfaces, pyrolusite, hematite, rare limonite. Locally plag → clay.

COMMENTS

527' Bit #1. HQ core bit. Christensen gray impreg. (393T)

0-827': 4" casing hung from 7" casing

core drilling w/ bentonite + polymers

589' - Bit #2 (same specs as #1) Bridge @ 575' on RIH

733' - Directional survey 2.5° S13E

859' - Bit #3 (same specs as #1)

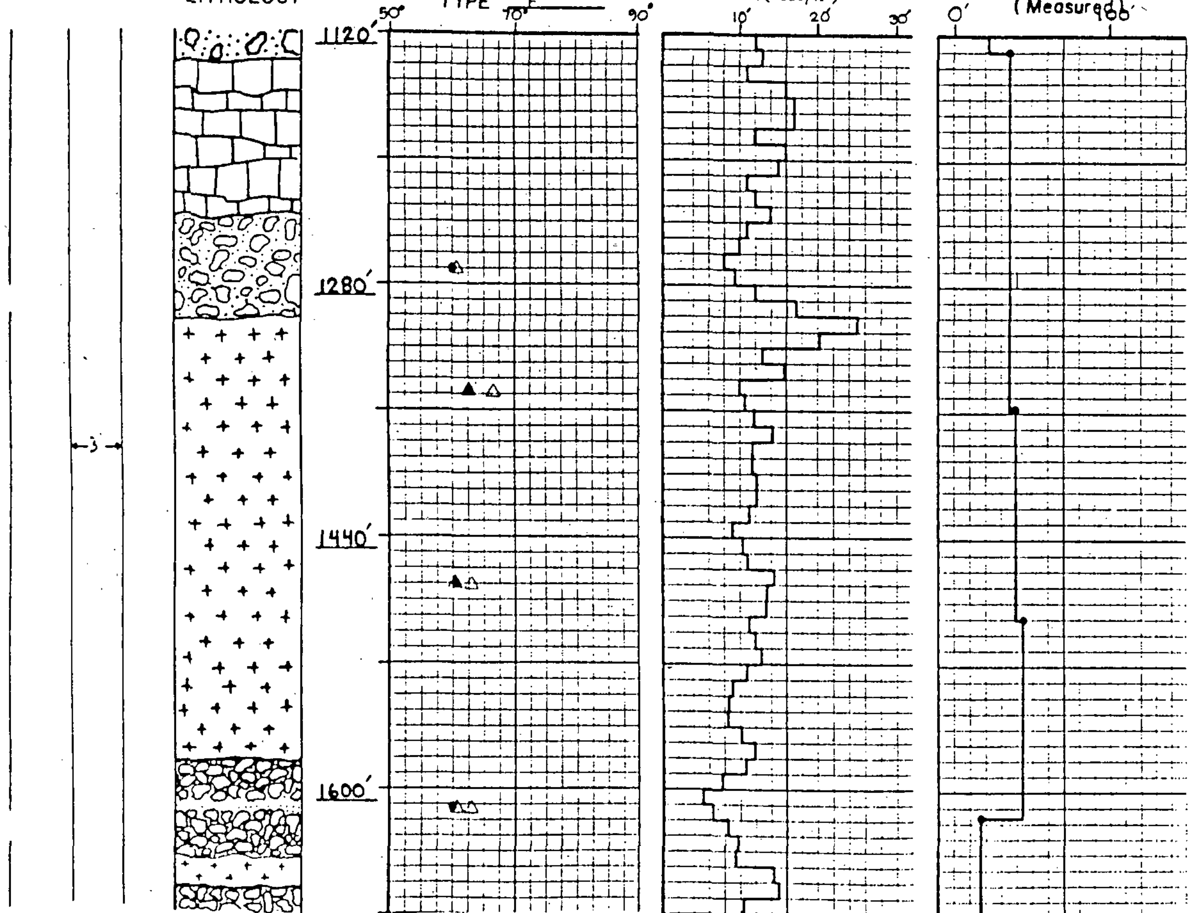
947' - Tripped to grease rods to alleviate rod chatter. Bridge @ ~600' on RIH. Core barrel sanded in. Tripped rods. Bridge @ ~600' on RIH.

Diamond Shamrock
Thermal Power Company

HOLE	CTGH-1	SPUD DATE	6/7/86	COMPLETION DATE	7 Sept '86
FIELD	CASCADES/CLACKAMAS	COUNTY	MARION	STATE	OREGON
LOCATION	Sec. 28, T8S, R8E	ELEVATION	3840'	☐ KB of ____ ☒ GL	
CONTRACTOR / RIG	BOYLES BROS / 882			GEOLOGIST (S)	GOODWIN/McDANNEL

TOTAL DEPTH: 4800 feet
TOTAL VERTICAL DEPTH: n/a
BOTTOM HOLE LOCATION: —
DATE:

CASING PROFILE | LITHOLOGY | DEPTH | DRILLING TYPE | TEMPERATURE °F | PENETRATION RATE (feet/hr) | WATER LEVEL (Measured) | LOST CIRCULATION ZONES | LITHOLOGIC DESCRIPTION | COMMENTS



● MUD IN
○ MUD OUT
■ MAKE UP H_2O
△ MRT to BH

● Measured w/pipe in hole after hole static 15 minutes

LOST CIRCULATION ZONES: Total fluid loss continu[es]. Pump rate varies: daily average 10-14 gpm

LITHOLOGIC DESCRIPTION:

1230' VOLCANIC BRECCIA Red-orng-brn. Lapilli to block size rock fragments of mafic lava(s) in matrix of ash (altering to clay), ash sz rock frags, & crystals. Variable clast size, clast : matrix ratio, & laminated intervals form 16cm-1.8m subunits. Origin of unit may be surge & airfall deposits. Numerous rubbly intervals. Pale orng-pnk clay, locally heavy. Tr FeOx/MnO.

1291' ANDESITE med brn to dk gry. 2-4% phenos: plag, opx, cpx, Hbl (≤4mm). Mnr plag → clay. Pale orange pink clay commonly coats fractures, forms seams. Tr pyrolusite, tr platy metallic min, hematite, clear to white tabular mineral (v. fine) in veinlets & on fracture surfaces. Intense fracturing, predom vertical; more variable w/depth: 30°, 45°

1570' VOLCANIC BRECCIA Md dk gry & gru brn. Lapilli & block sz rock fragments of mafic-intermediate lavas in matrix of ash sz rock fragments, clay (from ash?), & crystals. Unit changes character throughout its thickness: thin, cross-bedded, laminated intervals; palagonitic intervals, intervals of basaltic andesite lapilli & blocks w/features suggesting deposition while molten/plastic. Pyroclastic & surge origin is suggested by most of unit characteristics. Pale blue - blu gry clay on fractures, fine, clear acicular zeolite. FeOx.

1647' ANDESITE olive gry, med gry, brn gry. ≤1% phenos plag, pyx. Platy frac. @ 45°. Lt brn, dk grn gry clays coat fracs. Pyx → grn clay (ν/a). Tr limonite, MnO (pyrolusite) on fracture surf.

1666.5' VOLCANIC BRECCIA Lapilli - small block sz heterolithologic volcanic rock fragments in wachi to clayey matrix. Unit varies based on fragment size, matrix clast ratio; laminated cross-bedded intervals. Some mafic lava fragments appear to have been deposited while molten/plastic. Pyroclastic origin suggested for unit. Fracture minor w/variable direction. Trace fine, clear drusy zeolite on fractures

COMMENTS:

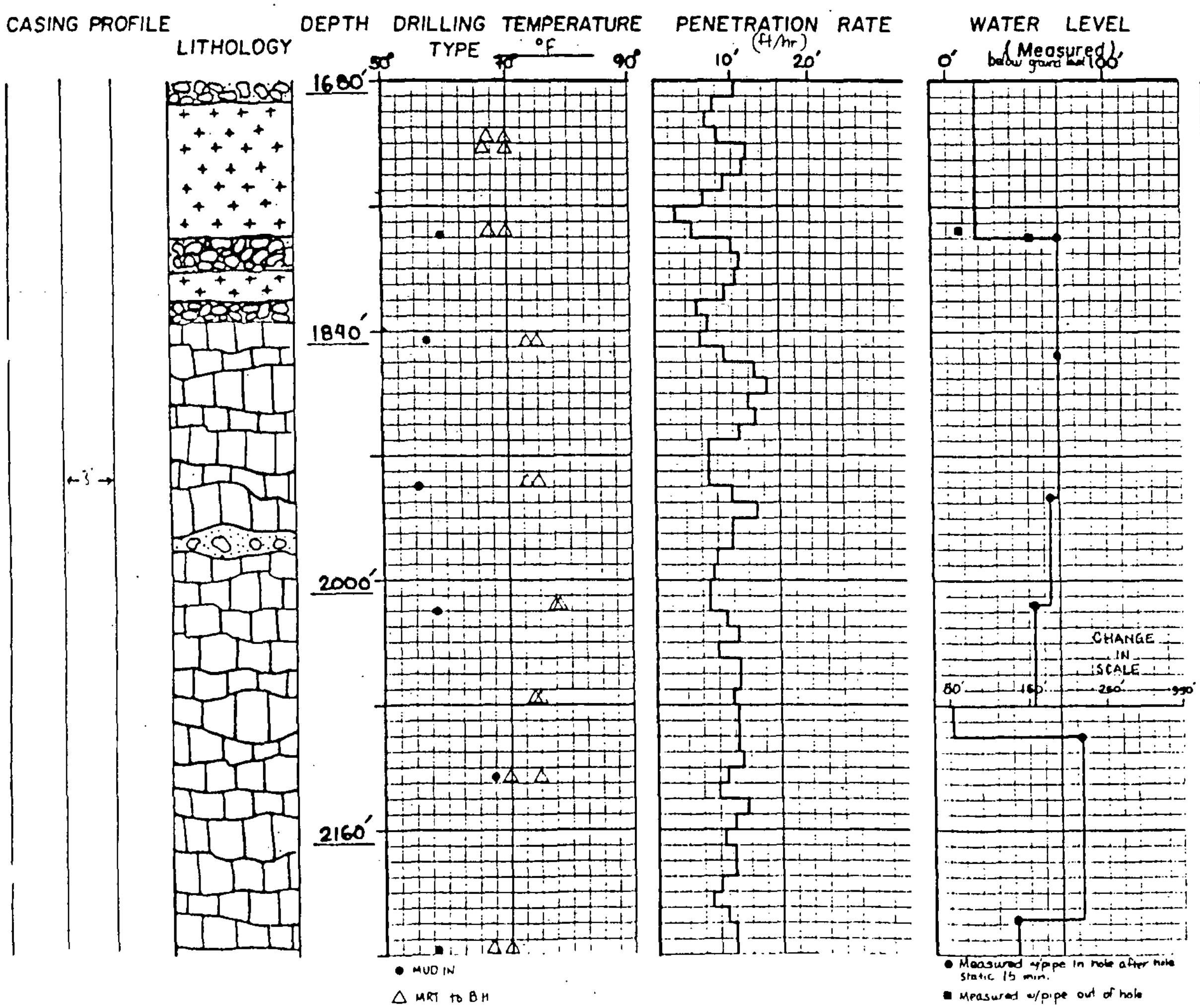
1271'. Bit #3. Same specs as bit #1. On RIH cave @ 600', 880', 920'

1620' Directional survey ½° N39E

Diamond Shamrock
Thermal Power Company

FORM 4

HOLE CTGH-1 | SPUD DATE 6/7/86 | COMPLETION DATE 7 Sept '86 | TOTAL DEPTH 4803 feet
FIELD CASCADES/CLACKAMAS | COUNTY Marion | STATE Oregon | TOTAL VERTICAL DEPTH n/a
LOCATION Sec 28, T8S, R8E | ELEVATION 3840' | ☐ KB of ____ ☐ GL | BOTTOM HOLE LOCATION —
CONTRACTOR / RIG Boyles Bros. / 882 | GEOLOGIST (S) McDannel/Goodwin | DATE



LOST CIRCULATION ZONES

Total fluid loss continues. Pump rate varies: daily average 10-14 gpm

2111' pump pressure dropped to zero (while pumping ~13 gpm) @ vertical fracture near flow contact. Subsequent H_2O level measurements indicate an initial 170'+ drop in hole fluid column followed by a slow rise over following days.

LITHOLOGIC DESCRIPTION

1694' ANDESITE. Med to dk gry to brn gry, porphyritic 1-3%, phenos plag, pyx. Lt - mod clay on fracture surfaces. Tr MnO. pyx → clay Generally very frac. Most prominent frac. 45°

1781.5' VOLCANIC BRECCIA
Med rd brn - md dk gry. Lapilli & blocks of scoria & andesite rock fragments in a sparse matrix of ash & clay. Pale brn, lt brn, brn red, & lt gry grn clays fill vesicles & lightly coat fractures. Clear, drusy zeolite on fractures. Unit has pyroclastic origin.

1798' ANDESITE Brn gry to med gry Sparsely porphyritic ≤1% plag, pyx Plag & pyx → clay Vesicles common. Clay (grn gry) on frac. surfaces & filling vesicles. Tr zeolite (?)

1820' VOLCANIC BRECCIA
Mod dk yel, orng brn, red brn Coarse ash & lapilli sz heterolithologic rock fragments & minor lt gry pumice in a matrix of ash, glass fragments & xtls. Changes in color, clast: matrix ratio clast size gives crudely bedded appearance to unit. Mnr shear on fracture surfaces. Origin of unit appears to be pyroclastic airfall.

1826' BASALTIC ANDESITE
Dk gry, finely porphyritic (2%) Phenos plag, cpx Mod clays; 40°-50° prominent fracture direction. Few fractures.

1969' VOLCANIC BRECCIA
to 1971 red brn Lapilli to coarse ash sz rock frags of intermediate to silicic composition in fine matrix of ash, & less commonly, ash sz rock frags. Crude bedding n/a @ 1970' to 1979. Basaltic andesite blocks & lapilli, often vesicular & apparently deposited while plastic, in mnr matrix of yel brn ash. Shear common on frac surfaces.

1979' BASALTIC ANDESITE
brn gry - gry brn, finely & sparsely porphyritic, commonly brecciated. Phenos plag, pyx, ol ? Mod.- heavy clays Clear drusy zeolite coats fracture surfaces. Much of unit is intensely fractured & brecciated & has greyish grn to dusky grn color. Fracture angles 15°, 40°, 80°

2036' BASALTIC ANDESITE
Grnish blk - dk grn gry - gryish brn, mnr red brn. Aphanitic to sparsely porphyritic. Fracture

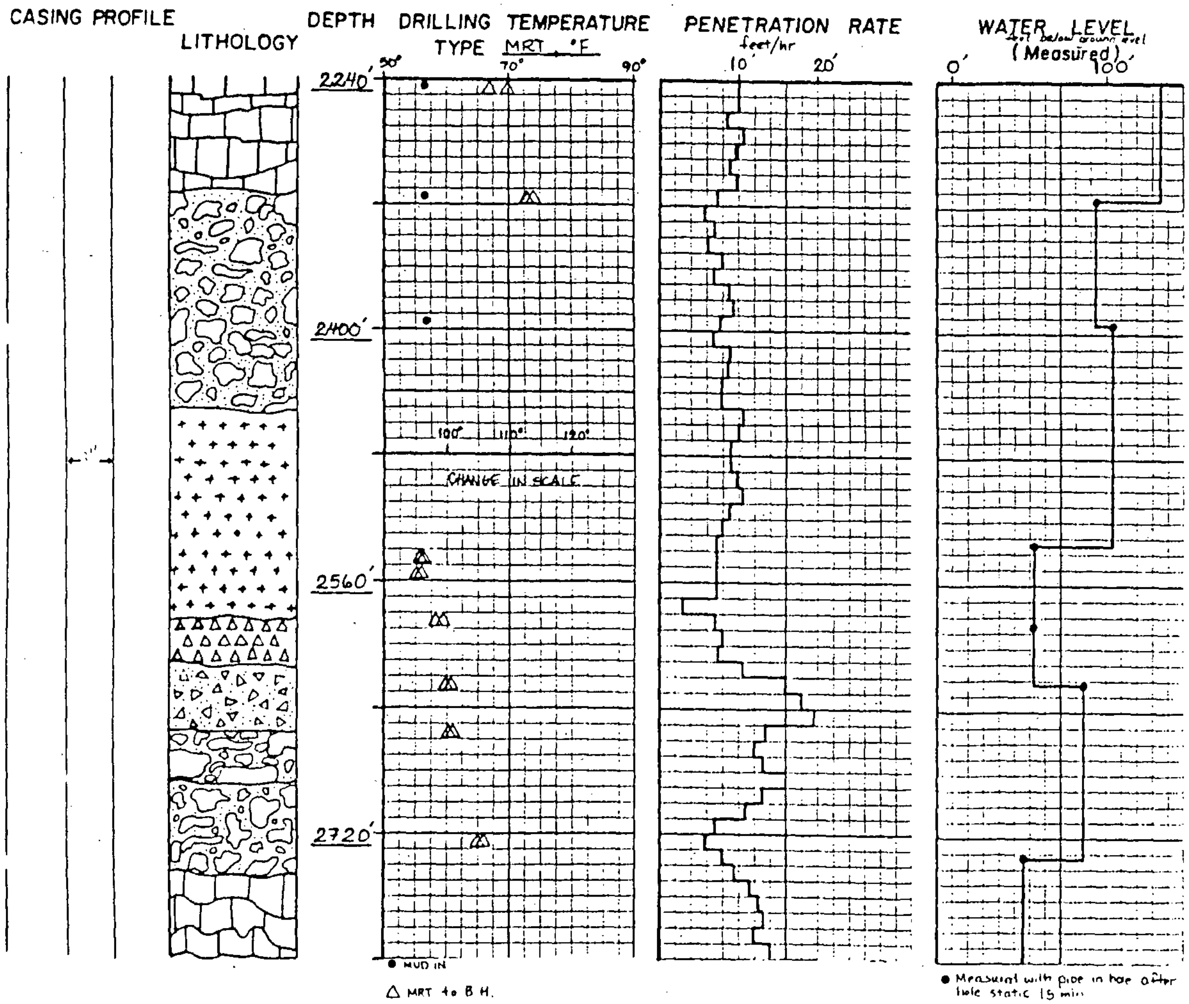
COMMENTS

1775' - Bit #3. Same specs as bit #1. On RIH encountered cave @ 615', 675'; 2' fill @ BH.

Lithology cont'd:
locally heavy. Predominately 45° vertical. Clays coat fracture surfaces Zeolites in fractures & coating surfaces Breccia common. Series of flows w/contacts (~ 2067', 2074', 2088', 2091, 2111', 2186', 2241) marked by oxidation & vesicles

Diamond Shamrock
Thermal Power Company

HOLE CTGH-1
SPUD DATE 6/7/86
COMPLETION DATE 7 Sept '86
TOTAL DEPTH 4800 feet
FIELD CASCADES/CLACKAMAS
COUNTY MARION
STATE OREGON
TOTAL VERTICAL DEPTH n/a
LOCATION SEC. 28, T8S, R8E
ELEVATION ~3840'
☐ KB of ____ ☐ GL
BOTTOM HOLE LOCATION ——
CONTRACTOR / RIG BOYLES BROS / 882
GEOLOGIST (S) GOODWIN / MCDANNEL
DATE



LOST CIRCULATION ZONES

Total loss continues, n/a

LITHOLOGIC DESCRIPTION

2317' VOLCANIC BRECCIA
Dk grn gry, md dk gry, gry red, mod red brn to brnish gry.
Lt-med gry angular to subangular lapilli to block sz rock fragments of mafic to intermediate lavas in a matrix of ash sz rock fragments, ash, mnr crystals, dk grn clay. Frequent intervals of red & black flow banded lava, often with irregular, disrupted margins suggesting molten deposition. Most of unit appears to have pyroclastic origin. Mnr intervals of homogeneous aphyric basaltic andesite. Mnr clay, predominately green, on fracture surfaces. Irregular fracture, often w/waxy, sheared surfaces. Mnr zeolites.

2453' ANDESITE
Md dk gry - v. lt. gry, porphyritic 10% phenos: plag, cpx, opx. Phenos are altering to clays. Localized fracturing/brecciation. Pervasive pale blue & pale green clay.

2550' ANDESITE
Md dk gry - rd brn. Sparsely & finely porphyritic. 2-3% phenos: plag, Hbld, pyx. Lt clay alteration. Grn gry & wht clay veinlets. Localized, intense fracturing.

2586' CRYSTAL-LAPILLI TUFF
Lt-md gry, red brn lapilli sz rock fragments, mnr lt gry collapsed pumice lapilli in orng brn to lt brn matrix of predom xtls, w/coarse ash sz rock frags. Unit is not welded, but is consolidated. Origin is probably air fall. Lt shearing. Dk grn & pale blue clay on fractures.

2602.5' LAPILLI TUFF
Lt gry angular to sub-rounded lapilli sz rock fragments, green black glass. Collapsed pumice?, in med gry-dk gry matrix of ash sz rock frags, ash, xtls & glomerocrysts of plag, opx, magnetite. Mnr clay. Mnr sorting/bedding. Ash-flow origin?

2657' ANDESITE BRECCIA
Unit is a series of volcanic breccia (pyroclastic origin, in part) & dense flow intervals. Breccia is consolidated but contains intergranular voids. Mnr wht & pale grn clay, zeolites in vesicles & voids. Mnr. fracturing.

2694' VOLCANIC BRECCIA
Lt-md gry block & lapilli sz rock

(Lithology cont'd)
fragments of mafic-intermediate lavas in a fine matrix of ash sz rock frags, mnr crystals, [illegible]. Mnr, localized [illegible] clays. Mnr [illegible] beds. Unit is predom matrix supported. Origin is probably pyroclastic & may be in part [illegible] or surge deposit. Intervals w/ lapilli - coarse ash fragments plastically deformed & w/ disrupted margins suggest deposition while [illegible].

2726' BASALTIC ANDESITE
Md dk gry, v finely porphyritic. 7-8% phenos plag, cpx & [illegible], ol? Tectonically brecciated intervals w/mnr dk gry grn clay. Minor movement in brecciated intervals. Lt-mod fracturing. [illegible] grn & gry grn clays.

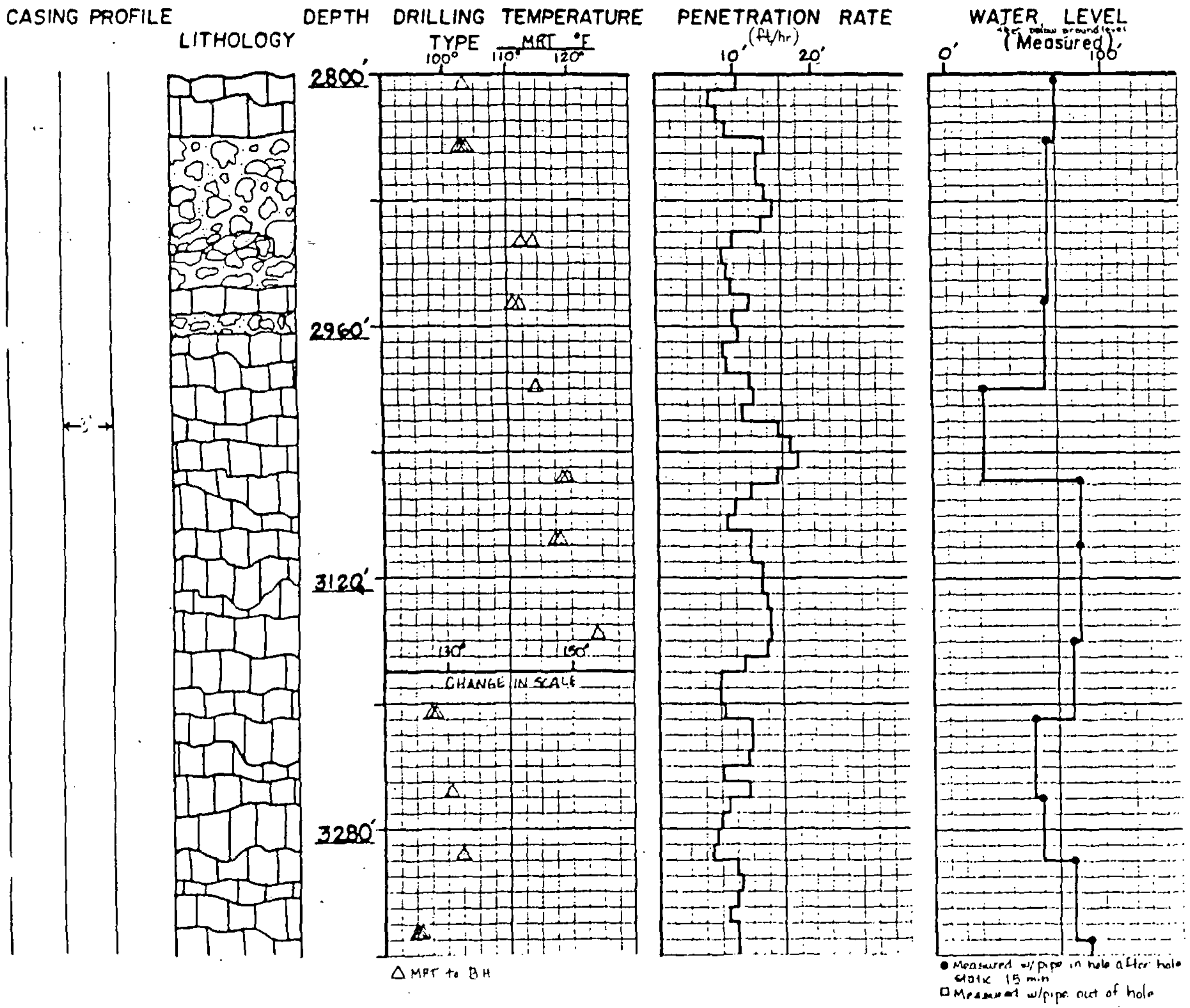
COMMENTS

2336' Bit #6 (same specs as bit #1). On R/H bridges @ 860' & 1140'

2486' Directional survey: 4°, N12E

Diamond Shamrock
Thermal Power Company

HOLE CTGH-1 SPUD DATE 6/7/86 COMPLETION DATE 7 Sept '86 TOTAL DEPTH 4900 feet
FIELD CASCADES/CLACKAMAS COUNTY MARION STATE OREGON TOTAL VERTICAL DEPTH n/a
LOCATION Sec 28, T8S, R8E ELEVATION 3840' ☐ KB of ___ ☐ GL BOTTOM HOLE LOCATION ———
CONTRACTOR / RIG BOYLES BROS. / BB2 GEOLOGIST (S) GOODWIN / McDANNEL DATE



LOST CIRCULATION ZONES

Total loss continues. 7-14 gpm.

LITHOLOGIC DESCRIPTION

VOLCANIC BRECCIA
2842' Angular to sub-rounded lapilli & mnr blocks of mafic-intermediate lavas in dk gry-brn gry-gry red matrix of smaller rock frags, xtls, clay. Unit varies from clast to matrix supported. Intervals of basaltic andesite w/elongated, disrupted margins in oxidized reddish brn matrix suggest deposition while molten. Mnr discontinuous grading forms bedding in matrix. Rare zeolites in fracs & mnr drusy coatings on surfaces. Light, variable fracture.

2935 BASALTIC ANDESITE
Med dk gry - med red, finely & sparsely porphyritic, ≤ 1% phenos: plag, pyx

2951.5 VOLCANIC BRECCIA
As above in 2842, but predom. clast supported

2965.5 BASALTIC ANDESITE
Med-dk gry - brn gry, finely & sparsely porphyritic (2-5%) Phenos: plag, pyx, both → clay. Much of unit is pyroclastic breccia - often as thick deposits: dk gry - brownish gry blocks & lapilli of basaltic andesite fragments in gry-red matrix of basaltic andesite lava. Mnr agglomerate. Overall fracturing is light and is much more common in dense lavas than in breccia. Most common fracture directions vertical & 45°, rarely 30° & 60°. Waxy "clays" common: dk gry grn, gry blue grn, bluish gry, pale blue. Other less common clays wht & gry brn gry. Clay may take botryoidal form, particularly in voids. Zeolites common (2990') often as drusy coating. Silica appears @ 3148' as veinlets & void fill. Often white & blue, & may replace "clays". Native copper as small plates & thin wire (microscopic) appears @ 3248'

COMMENTS

3300' Directional survey 3/4° N16W

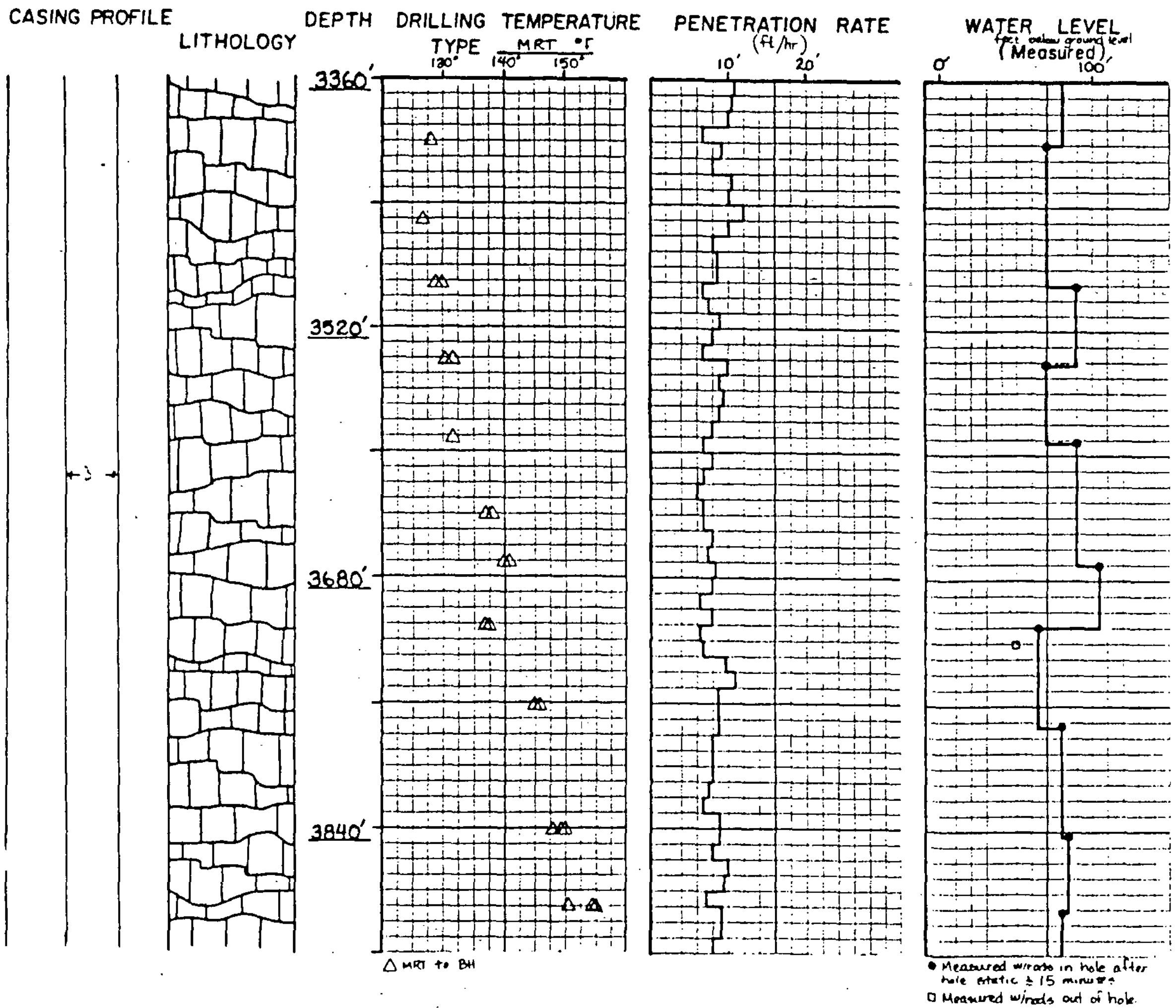
Diamond Shamrock
Thermal Power Company

HOLE CTGH-1 | SPUD DATE 6/7/86 | COMPLETION DATE 7 Sept '86 | TOTAL DEPTH 4800 feet

FIELD CASCADES/CLACKAMAS | COUNTY MARION | STATE OREGON | TOTAL VERTICAL DEPTH n/a

LOCATION SEC 28, T8S, R8E | ELEVATION ~3840' | ☐ KB of ____ ☐ GL | BOTTOM HOLE LOCATION ——

CONTRACTOR / RIG BOYLES BROS / 882 | GEOLOGIST (S) McDANNEL/GOODWIN | DATE



LOST CIRCULATION ZONES

Total loss continues 7-14 gpm

LITHOLOGIC DESCRIPTION

BASALTIC ANDESITE as above @ 2965.5 cont'd: Thin (2'-10') dense flows of sparsely & finely porphyritic basaltic andesite interlayered with thicker intervals (2'-25') of basaltic andesite volcanic breccia. Fracturing is light to moderate, w/local heavy facture zones, & is more common in flows than breccia. Fracture direction is variable, but vertical - sub-vertical direction is most common. Green & blue "clays" common, filling voids & coating fracture surfaces. Dark grn & blue grn "clays" effervesce (lightly) w/HCl. White & gry brn clays are less abundant & were deposited subsequent to grn & blue clays. (Light blue clays subsequent to dk grn, gry grn, blue grn). Silica fills voids, fractures & may replace some clay. Silica more common in lava flows than breccia. Zeolites occur as very fine crystals (clear) forming drusy coating on grn & blue clay; acicular & fibrous varieties are common in voids & may coat grn/blue clays. Silica & zeolites deposited subsequent to grn & blue clays. Microscopic native copper 3248-3700'. Minor yellow & orange FeOx stains.

COMMENTS

3721 Bit #7 (same specs as core bit #1). Cave between 800-1,000' on RIH.

Diamond Shamrock
Thermal Power Company

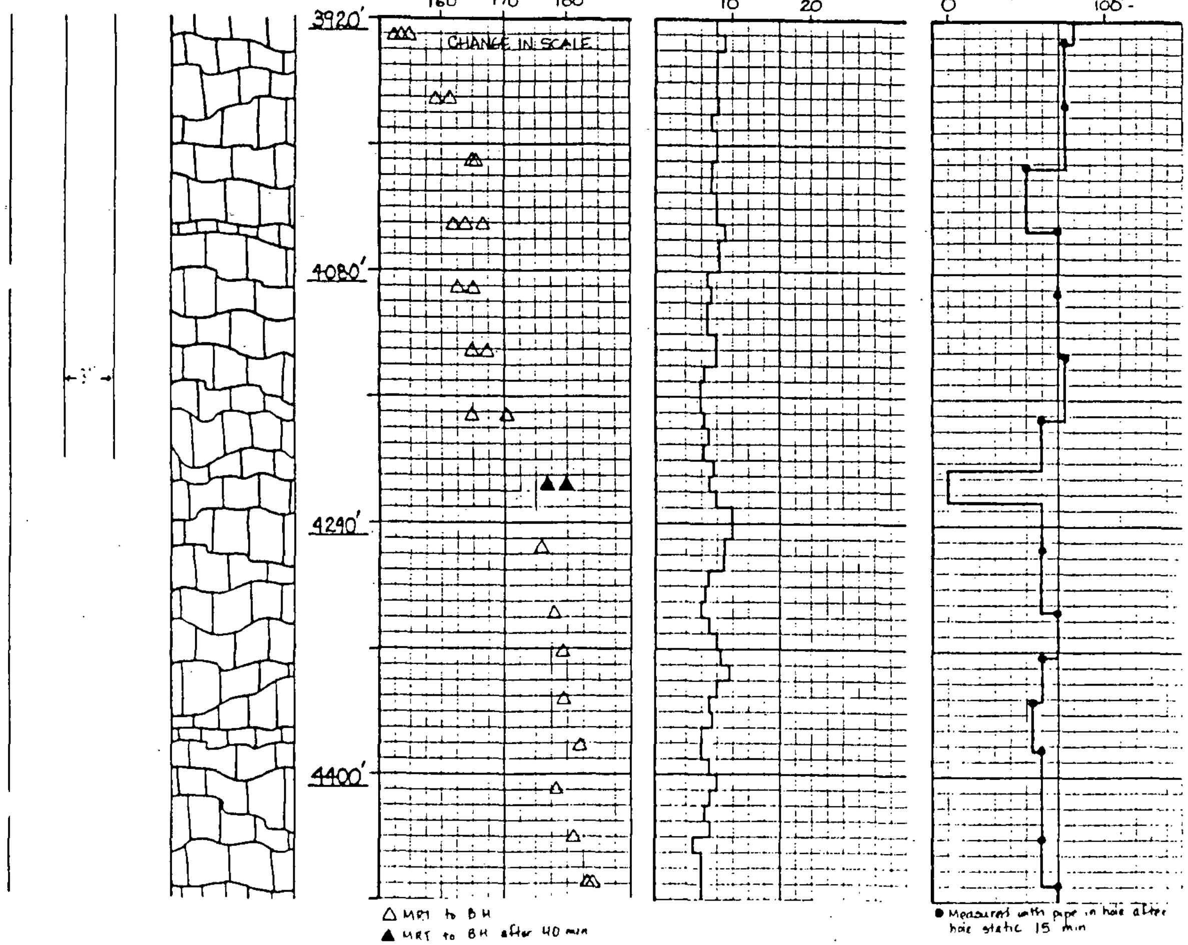
HOLE CTGH-1
FIELD CASCADES/CLACKAMAS
LOCATION SEC. 28, T8S, R8E
CONTRACTOR / RIG BOYLES BROS. / 882

SPUD DATE 6/7/86
COUNTY MARION
ELEVATION ~3840'

COMPLETION DATE 7 Sept '86
STATE OREGON
☐ KB of ___ ☐ GL
GEOLOGIST (S) GOODWIN / McDANNEL

TOTAL DEPTH 4800 feet
TOTAL VERTICAL DEPTH n/a
BOTTOM HOLE LOCATION —
DATE

CASING PROFILE | LITHOLOGY | DEPTH | DRILLING TEMPERATURE (TYPE, MRT °F) | PENETRATION RATE (ft/hr) | WATER LEVEL below ground level (Measured)



LOST CIRCULATION ZONES

Total loss continues. 7-14 gpm

4206'-4226' full returns.

4226' Total circulation loss resumes. 7-14 gpm

LITHOLOGIC DESCRIPTION

BASALTIC ANDESITE (as above)
Dense flows of sparsely & finely porphyritic lavas of basaltic andesite interlayered with volcanic breccia of same composition. Lavas are slightly thicker (up to 14'-20') and breccias thinner (6'-8') than above. Fracturing is light to moderate and is more common in lava flows than breccias. Fracture direction variable; it is commonly high angle (0°-20°). Green & blue "clays" common, filling voids & coating fracture surfaces. Dark grn & blue grn clays effervesce lightly w/HCl. White & brown clays less abundant. Silica fills voids, fractures & may replace some clay. Silica most common in lavas. Zeolites are common & fill voids lined by clay. Minor yellow & orange FeOx stains follow fractures.
Order of deposition of clays & secondary minerals
Dk green clay, light green & blue green clay, ± silica, ± zeolites, ± brn & wht clays.

COMMENTS

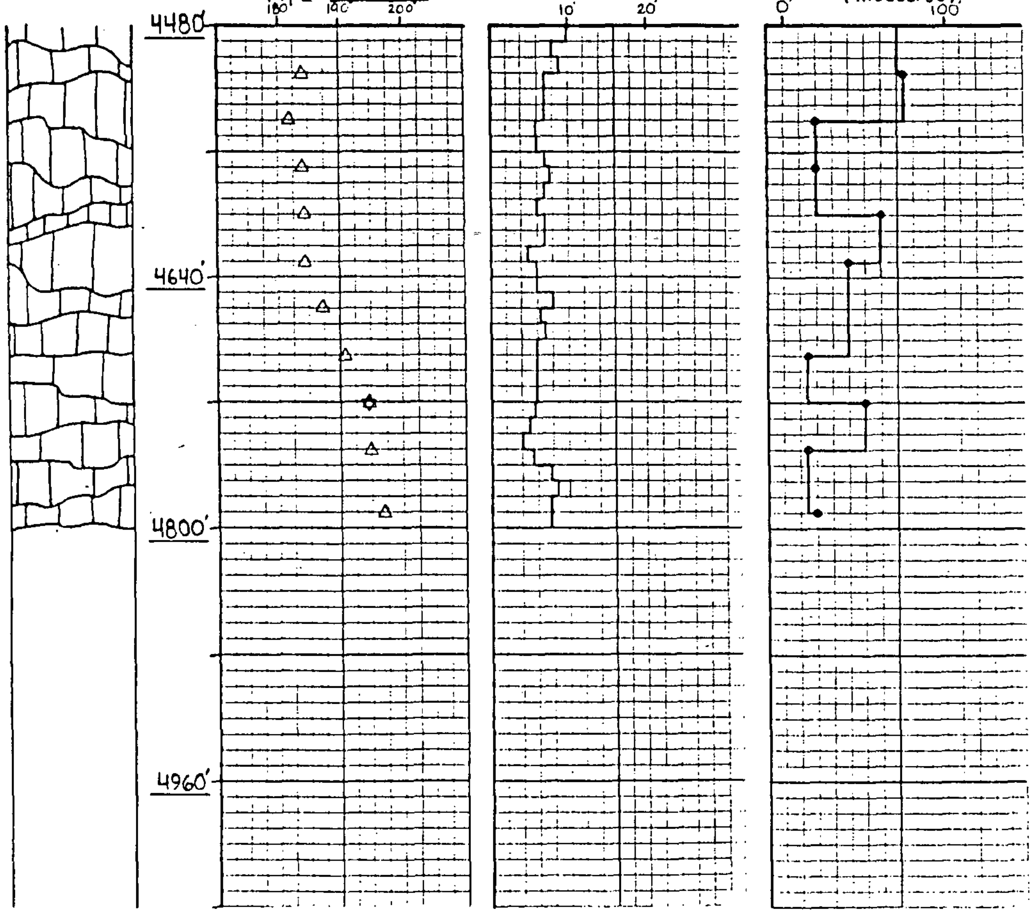
4206' Twisted off @ 823' below ground level. Entered H-rods w/NX rods to retrieve inner core barrel. Returned into H-rods w/NX rods & bit #8 (Christiansen grey imp [illegible]), drilled out H-bit (#7) & proceeded drilling to 4226'.

4226' Tripped out of hole. RIH w/bit #9 (same specs as #8)

Diamond Shamrock
Thermal Power Company

HOLE CTGH-1 SPUD DATE 6/7/86 COMPLETION DATE 7 Sept '86 TOTAL DEPTH 4800 feet
FIELD CASCADES/CLACKAMAS COUNTY MARION STATE OREGON TOTAL VERTICAL DEPTH a/a
LOCATION SEC 28, T8S, R8E ELEVATION ~3840' ☐ KB of ____ ☐ GL BOTTOM HOLE LOCATION —
CONTRACTOR / RIG BOYLES BROS/882 GEOLOGIST (S) ____ DATE ____

CASING PROFILE | LITHOLOGY | DEPTH | DRILLING TYPE | TEMPERATURE MRT °F | PENETRATION RATE (feet/hour) | WATER LEVEL (feet below ground) (Measured) | LOST CIRCULATION ZONES | LITHOLOGIC DESCRIPTION | COMMENTS



△ MRT TO BH
✡ MRT TO BH AFTER HOLE STATIC 4 HRS

● Measured with pipe in hole, after hole static 15 min

Lost circulation zones: ~4480' pump rate increased to ~15 gpm due to high torque.

Lithologic description:

BASALTIC ANDESITE
(as above)
Dense flows of sparsely & finely porphyritic to aphyric basaltic andesite interlayered with volcanic (pyroclastic), breccia. In the lower 500-400' of the unit breccias are generally thicker than flows. Flows are often as thin as 4'-6'. Fracturing is generally light & concentrated in the flows. Grn & blue clays common as void fill & fracture coatings (light). Silica fills voids & fractures & is much more common in lavas than breccias. Zeolites are common, particularly in breccias. Clays typically precede zeolites & silica. Silica (hudness) may coat some zeolites. Mnr yellow & orange FeOx stains & clays along fractures; these are typically localized in their occurance. Fracture surfaces are typically sheared & may have mnr serpentine & hematite

A PRELIMINARY REVIEW

OF THE

SECONDARY MINERALOGY IN DRILL HOLE CTGH-1

for

THERMAL POWER CO.

Santa Rosa, California

by

Columbia Geoscience

Hillsboro, Oregon

September 1986

A Preliminary Review

of the Secondary Mineralogy in Drill Hole CTGH-1

Thermal Power Co. geothermal exploration hole CTGH-1 was spudded on the 7th of June 1986. The hole was drilled with a rotary bit from the surface to 527 ft. From 527 ft. to a total depth of 4800 ft. the hole was cored. The well site geology and core logging was done by Angela McDannel and Doug Goodwin.

Thermal Power Co. contracted with Columbia Geoscience to visit the well site as requested, for a planned maximum of 5 visits between the spud date and T.D. (7 June-27 August) .The visits were designed primarily to conduct a hand lens level review of the secondary mineralogy, with additional binocular microscope review of select samples, in order to give a first-level interpretation of current and past hydrothermal activity. Petrographic interpretations are to be covered by other contractors. Contractual constraints on time permitted only discontinuous spot observations of the core rather than a complete review.

The rock encountered in drill hole CTGH-1 is predominantly volcanic with some possible subvolcanic units. The primary volcanic features observed in the core include lava flows, pyroclastic airfall deposits, agglutinates, palagonitic tuffs and subaerial density flow deposits. Non-primary igneous features include glacial till, lahars and conglomerates. Two general types of fracturing and brecciation are observed in the core. The first can be considered as basically primary volcanic features, and includes cooling fractures, flow autobreccias and agglutinates. The second type is the result of tectonic movement and includes fracturing and fracture/fault brecciation. This latter type is common throughout much of the hole and generally displays a vertically oriented set of fractures. The primary features provide good permeability in the shallow portion of the hole. This permeablilty decreases with depth as lithostatic pressure and lithification of clastic horizons increases. The potential for tectonic fracture related permeability should remain rather constant throughout the hole, with some consideration for physical rock characteristics. Brittle flow and subvolcanic rock break to form fracture and breccia zones when sujected to stress. These fractures have the potential for permeability and indeed can be observed to maintain open zones in some core fragments. Clastic rock, especially tuffaceous rock, tend to undergo plastic deformation rather than mechanical failure when subjected to stress. The clastic zones, then, would be likely to create an aquifuge.

Translucent to opaque soft waxy gouge is observed to be a common feature to most of the tectonically fractured and brecciated areas. It is usually developed to only a few mm thick along most fracture surfaces and usually displays well developed slickenside striations. In a few places intense zones of brecciation have resulted in the development of protomylonite. These most intensely developed fault-breccia zones occur most commonly between the 2000 to 3000 foot interval. The color of the gouge tends to be dark brown and green to black when occurring in brittle flow and subvolcanic rocks. The color of the gouge is more often brown to yellow to orange when occurring in tuffaceous rock.

Four catagories of secondary mineralization are apparent in the core from CTGH-1. The first type involves the alteration of basaltic glass to palagonite during the formation of tuffs and related volcanic features. Water plays a major role in the alteration of the glass to palagonite and related clays and colloids. This type of alteration occurs during and immediatly following eruptions. The second type of mineralization involves the alteration of the volcanic rock to hematite, zeolite and clay by downward perculating oxygen-rich meteoric water. Examples of this type of alteration include rock at the 1306 ft., 2736 ft. and 4765 ft. depths. The third type of mineralization consists of the mechanical and chemical alterations associated with gouge resulting from tectonic induced shearing and faulting. In varying degrees the gouge is represented throughout much of the hole. The fourth type of secondary mineralization consists of the precipitation minerals forming in vesicles and along fractures as the result of rock-water reactions. The second and fourth types of secondary mineralization, host rock alteration and precipitation minerals, allow constraints to be placed on possible hydrothermal events.

The range of precipitation minerals observed in the core from CTGH-1 include clay, zeolites, silica and native copper. Precipitated clay occurs as thin vesicle and fracture coatings. Often two distinct layers of clay with different colors suggests two episodes of clay precipitation. Clay is also observed to partially to completely fill vesicles. These clay fillings often display horizontal 'bedding' features. These features are commonly normal to the axis of the core; though in a few fragments they are as much as 20^{o} off normal. Clay mineralogy can not functionally be discerned at the hand lens and binocular microscope levels. The majority of the clays are probably smectite. The varying darker green colors of some of the clays suggest an iron component. Mixed layered smectite-chlorite should be considered a possibility for some of the clay toward the lower portion of the hole.

Zeolites are observed as precipitation minerals forming both in vesicles and on fracture surfaces. Often the crystal size of the zeolites is quite small, making crystal habit and morphology determinations tentative at best. Three morphologies of zeolites are recognised in the core from CTGH-1. A zeolite with cubic morphology, most easily observed in the central portion of the hole, appears to be part of the analcite-wairakite series. A zeolite with an acicular or fiberous morphology, obeserved irregularly throughout much of the hole, appears to be part of the natrolite-scolecite series. A zeolite with a tabular morphology, more prevelant in the lower portion of the hole, is tentatively identified as heulandite. The acicular zeolite usually represents the last episode of precipitation and often forms subsequent to the cubic zeolite. The tabular zeolite is often observed in association with cryptocrystalline silica.

Silica is observed to form in vesicles and more commonly in fractures in the lower portion of the hole. The most common morphologies of silica are botryoidal to spherical features less than a few mm thick with a texture of opal or beta crystobalite. Thicker deposits of silica, up to four or five mm thick in a few fractures, show a somewhat coarser texture suggesting chalcedony.

Small bladed aggregates of native copper are observed in the areas around 3300 ft. and 3700 ft. These sub-mm blades occur on the surfaces of precipitated clay along fractures and less commonly on precipitated zeolites in vesicles and fractures. In most instances the copper blades have formed subsequent to other mineralization.

The degree of alteration within the flow and subvolcanic rocks of the core from CTGH-1 includes both oxygen-rich (hematite and zeolite) and oxygen-poor (reduced Fe-bearing clay) characteristics. The intensity of the alteration varies throughout the hole and ranges from fresh minimally altered to extensively altered rock. While the degree of alteration is variable from place to place within the hole, the degree of alteration shows little variation between areas near potentially permeable fractures and vesicles areas away from these potentially permeable features. The type of alteration relative to the oxidation state also tends to show little or no variation within a given rock with regard to proximity of potentially permeable features. The limited wall-rock mineral reaction suggest that the zeolites are the result of local cation migration and are probably toward the Ca-rich end of each series. Heulandite and natrolite-scolecite are characteristically stable in low temperatures. Analcite-wairakite has been observed to form at both low and high temperatures.

The secondary minerals suggest no major cation migrations which would involve introduction or removal of cation populations to or from the area. The secondary mineral suite does suggest a condition of near thermal equilibrium between the rock and water as the precipitation minerals formed in vesicles and fractures. Both the volume and the chemical constituents of the secondary minerals observed in the core can most easily be explained by local metasomatization rather than by major convective fluid movement. The presence of fresh copper crystals places limits on the stable chemical environment, particularly on the partial pressures of O, S and CO_2. Downward percolating meteoric water would likely oxidize the copper. Upwelling geothermal fluids would likely recrystallize the copper as a sulfide or a carbonate.

The combination of mineral, chemical and thermal constraints suggests that the area has never hosted a major convecting hydrothermal system, in spite of the extensive fracturing and brecciation. These constraints also suggest that past regional temperatures in this area have probably never significantly exceeded current temperatures.

THERMAL POWER CO.

Exploration Hole CTGH-1

The following are notes and observations of selected portions of the drill core. The selection of observation points has been based on the lithology and notes of the well-site geologists. The footage notations indicate observation points rather than lithologic boundaries.

565 ft.

Gray to dark gray vesicular basalt. Sub-mm mafic crystals in the groundmass have undergone partial to complete alteration to hematite.

817.9 ft.

Light gray to light gray-purple volcanic breccia. The coarser fragments of this rock range from silicic to basic and from holocrystalline to hypocrystalline igneous fragments, and from angular to subrounded This zone could represent a lahar or possibly glacial till.

879 ft.

Gray diorite or dacite subvolcanic rock. A set of generally horizontal fractures display a black to reddish mineral that appears to be hydrous Fe oxide psuedomorphs after an Fe sulfide. A set of generally vertical fractures contains both the hydrous Fe oxide minerals and a light brown to buff clay. Alteration of the host rock is minimal; generally less than 1 mm deep along fracture surfaces.

1000 ft.

This is typical of a number of "breccia clay zones" mentioned in the field lithology notes. The breccia fragments have sharp angular features. The degree of alteration in the breccia fragments appears to be the same as the degree of alteration in unbrecciated portions of the rock. A light brown clay, often with horizontal layering, fills some open fracture areas within the rock. The clay does not appear to be an alteration product or a precipitation product. The clay appears to be soil derived clay and silt, possibly brought in by shallow ground water movement.

1047 ft.

Minor to trace metallic silver minerals are observed in the dacite (?) groundmass. These may be crysrals of primary specular hematite.

1082 ft.

The black mineral noted in the well-site logs along fracture planes appears to be hydrous Fe oxide rather than pyrolucite. This is possibly an alteration product of Fe sulfide. In a brecciated zone near 1082 ft. there may be traces of a black dendritic Mn oxide.

1109 ft.

This area is noted in the well-site logs as the base of a dacite flow. No flow banding, flow features, or vesiculation are observed. The boundary dacite texture shows autobrecciation with intense clay alteration. More solid blocks of slightly altered dacite are up to 5 cm across.

Underlying the dacite is a conglomerate with a few silt-rich zones displaying a bedded texture. Nearly to 1.5 m of the underlying unit has a noticeable reddish tint, possibly the result of Fe oxidation from contact thermal alteration.

NOTE: The 'dacites' and 'diorites' noted in the well-site logs may at least in part be subvolcanic bodies intruding uppermost Miocene or Pliocene volcanics at this depth.

1132-1137 ft.

Reddish (baked?) zone in 'conglomerate', underlain by a well lithified autobreccia appx. 6 ft. thick, grading into a 'flow'. No flow textures are readily noticeable in the 'flow' rock below 1139 ft. This may represent thermal contact alteration and autobrecciation associated with a subvolcanic feature.

1169 ft.

No flow texture or significant vesiculation is observed in this 'andesite'. It may be difficult to determine if this is part of a flow or a subvolcanic rock. Note possible relict hornblende crystals in rock.

1219 ft.

Light gray basalt. Rare traces of orange-brown iron oxide staining are observed. Plagioclase phenocrysts, pyroxenes and groundmass appear to be fresh.

1230-1244 ft.

A zone of possible autobrecciation with internal vesicular to scoriaceous fragments up to 4 cm across displaying welded or integrated boundaries rather than discrete rock fragment boundaries. The texture resembles that of an agglutinate. No flow textures are observed. In core specimens it will often be difficult to distinguish between flow autobreccias and agglutinates.

1291 ft.

Gray to dark gray, aphanitic basalt with irregularly distributed zones of clay and reddish hematite alteration.

1280-1300 ft.

The rock appears to be sheared and brecciated rather than a conglomerate as noted in the well-site logs. Two possible explanations for the brecciation are vertical shearing resulting from structural movement or shearing along the edge of a near vertical intrusive.

1306 ft.

Gray to dark gray andesite with irregularly distributed zones of clay and reddish hematite alteration.

1318-1325 ft.
A/A.

1331 ft.
Gray to light gray two-pyroxene(?) andesite. Groundmass and phenocrysts appear to be very fresh.

1404-1412 ft.
Core in this box is dominated by vertical fractures with fault gouge up to 1 cm thick in places. No major rock-water reactions are evident in spite of the abundant surface area resulting from brecciation.

1407.5 ft.
Tectonically brecciated fragments of andesite with slickenside features along some fracture surfaces. Hydrous iron oxide altered sulfides are common on fracture faces.

1430-1438 ft.
Rock is dominated by vertical fracturing. The clay observed in some of the open fractures is light brown and displays horizontal bedding features similar to that observed at 1000 ft.

1436 ft.
Gray to light gray porphyritic andesite. Rock is fractured, with the fractures lined by a light gray to gray-green clay, and orange to black hydrous iron oxide which is forming at the expense of Fe sulfides. The black hydrous Fe oxide has been noted as pyrolucite in the well-site geologic notes. Locally, some fractures contain a few millimeters of soft waxy gouge with slickensides. Clay alteration of groundmass and phenocrysts is limited but noticeable near fractures, and very sparce away from fractures.

1447 ft.
Sample of rock similar to the above description (1436 ft.). This specimen contains a single horizontal band of mm to sub-mm size irregularly shaped vesicles. No precipitation or alteration mineralization is noted to be specifically associated with the vesicles.

1576 ft.
Gray brecciated porphyritic basalt with orange to light brown clay filling fracture seams in the rock. Both mafic and plagioclase phenocrysts are moderately to strongly altered, with the plagioclase phenocrysts altering to clay and possibly zeolite.

1583-1589 ft.
The rock is dominated by abundant vertical fracturing. This basal portion of the flow is vesicular with irregularly shaped vesicles. The brecciated texture of the rock likely represents a basal flow breccia.

1592 ft.
Gray to orange-gray variably bedded ash and fine lapilli. The lapilli size fraction includes microporphyritic basaltic fragments and plagioclase and pyroxene crystal fragments. The yellow-orange altered

ash matrix suggests palagonite. Lenticular bedding and flame structures are evident in the core. This rock appears to be a primary volcanic subaerial density flow deposit rather than a lahar as noted in the well-site logs.

1601-1610 ft.

Lapilli- to ash-sized volcaniclastic fragments, including palagonite. The rock contains some fresh vesicular lapilli fragments. This appears to be a primary volcanic tuffaceous unit rather than a conglomerate as noted in the well-site logs.

1617 ft.

Gray scoria-rich unbedded basaltic tuff. Many scoria fragments contain fresh tachylyte. Sub-mm fragments of fresh tachylite are present in the matrix, though many of the ash-sized fragments in the matrix appear to have been altered to clay.

1629-1648 ft.

Palagonite-cemented basaltic tuff, grading into a more dense vesicular rock below about 1635 ft.

1666-1675 ft.

Vesicular basalt with a variable palagonite component.

1675-1684 ft.

A/A with increased vertical shearing. The shearing tends to obliterate some of the original rock texture.

1729 ft.

Tectonically brecciated basalt. A thin layer of soft, waxy gouge with identifiable slickenside texture covers the surface of the breccia fragments. A thin coating of clay has formed on some of the fracture surfaces subsequent to faulting. In a few of the fractures small black, dendritic mineralization is present.

1764.5 ft.

Gray tectonically fractured microporphyritic basalt. Fractures are generally steeply dipping. Fracture surfaces contain a thin coating of cataclastized rock displaying slickenside effects. The slickenside color is dark gray to dark olive-green with localized reddish zones, apparently associated with cataclastized mafic phenocrysts.

1780-1798 ft.

Rock is made up of descernible volcanic fragments welded in a matrix containing similar phenocrysts as the fragments. This may represent an agglutinate feature.

1820 ft.

Vertically fractured and brecciated flow overlying a crystal-lithic tuff.

1823 ft.

Orange to brown, crystal-lithic tuff. The crystal population includes fragments of hornblende, quartz, and feldspar (sanadine ?). The matrix and many lithic fragments have been altered to clay. Near-vertical fractures contain well developed slickensides indicating near-vertical movement. Subtle rock textures suggest plastic rock deformation in addition to fracturing.

1863-1871 ft.

Welded scoriaceous basaltic fragments. The welding of fragments suggests that this could be much more accurately described as an agglutinate rather than as a horizon of cinders as noted in the well-site notes.

1930-1948 ft.

Breccia from faulting and shearing continues to 1948 ft. Black waxy slickensides are present on the brecciated fragments as a result of shearing. There is no mineralogical indication that the rock has interacted with water or gas which was out of equilibrium with the rock.

1974-1984 ft.

Rock dominated by fractures ranging from 45° to vertical. Black slickensides are present as above.

1981 ft.

Dark gray to black, vesicular, aphanitic basalt. Some vesicles are partially to completely filled with a soft, waxy, dark gray-green clay. Minor, clear zeolites have formed in a few of the vesicles not totally filled with clay.

2036 ft.

The rock is strongly sheared and is variably palagonitic. Locally thin white stringers (zeolite?) follow along shear planes. No indication of any volcanic-related vapor phase minerals noted in the well-site logs are observed.

2038 ft.

Dark green-gray tectonically brecciated basalt (protomylonite). The matrix is a soft, waxy, green-gray to brown-gray, translucent, cataclastized rock. White zeolite stringers up to three millimeters thick are common.

2067 ft.

Dark gray to black, vesicular basalt. Many of the basalt vesicals are filled with a white acicular zeolite. A few of the vesicles are filled with a white to dark green clay, occasionally containing brown sub-millimeter spheres. Near-vertical fractures contain linings of clear, blocky zeolite overlying a thin, blue-green clay film.

2148 ft.

Dark gray, slightly vesicular basalt with vertically-oriented fractures. Occasional fractures are partially filled with a clear, blocky zeolite. The host rock shows variable clay and hematite alteration.

2177-2189 ft.

Vesicular lava with a 30 cm orange Fe oxidized zone. Vesicles increase away from the oxidized zone.

2189-2199 ft.

Lava with fracture-lining zeolites. Orange Fe-oxidized zones occur along fractures.

2196 ft.

Very dark gray, slightly vesicular, aphanitic basalt. Many irregular- to spherical-shaped vesicles are filled with soft, waxy clay. A few sub-rounded vesicles contain clear, blocky zeolite. Reddish hematite alteration of mafic minerals in the basalt is pervasive and clay alteration of the matrix appears to be common.

2321 ft.

Tectonically brecciated basalt (protomylonite). The matrix of the breccia consists of soft, waxy fault gouge, generally dark gray to dark gray-green, and locally reddish. In a few open fractures white blocky zeolite has formed on the slickensides.

2430-2449 ft.

A 30 cm thick soft zone has been disaggregated by the bit action. The color suggests that this zone may be palagonitic. The surrounding rock resembles an autobreccia or an agglutinate. The rock has been sheared with fractures running about 45^{o}. The well-site logs describe this as a bedded zone.

2458-2467 ft.

Reddish (hematite ?), welded breccia or agglutinate that has been strongly sheared. The well-site notes label this as andesite with palagonite. Nothing resembling palagonite is observed in this section. By in large, where spot checked, the well-site work has been labeling reddish Fe oxide zones as palagonite and has been labeling many palagonitic tuff zones as conglomerate or breccia.

2508 ft.

Fault gouge (protomylonite) that is generally light gray-green. Fractures within the fault gouge are partially to completely filled with an acicular zeolite.

2536-2543 ft.

Autobreccia or agglutinate with a reddish oxidized matrix referred to in the well-site notes as andesite with palagonite. No palagonite is observed (see note for 2458-2467 ft.). The apparently welded matrix contains both crystal, and very small lithic, fragments.

2658 ft.

Gray to gray-green, cemented basaltic ash and lapilli tuff. The ash -sized fraction appears to be devitrified. Fractures contain fine crystalline, blocky zeolites.

2718 ft.

Brown to orange, crystal-lithic tuff. Crystals include hornblende and clear feldspar. Lithic fragments appear to include both basalt and dacite. The matrix has been pervasively altered to a waxy, yellow to orange clay. The well-site notes describe this as a volcanic conglomerate.

2736.5 ft.

Light purple-gray, clay and hematite altered basalt/andesite. The rock is strongly fractured and locally cataclastized. Occasional open fractures are lined with a clear, blocky zeolite. A few fractures are filled with calcite. The calcite does not appear to be cogenetic with the zeolite.

2790.5 ft.

Sheared basalt with abundant soft, waxy, translucent, light to very dark gray-green fault gouge.

2813.3 ft.

Sheared gray basalt with waxy, light to dark gray-green fault gouge. Occasional open spaces in slickensides contain a clear, blocky zeolite. The fracture and shear planes generally run from 45° to near-vertical. The host basalt has undergone variable clay, zeolite, and hematite alteration.

2840-2850 ft.

The rock appears to be a strongly lithified conglomerate with rounded cobbles up to 12 cm. The matrix is both strongly clay altered and well lithified.

2860-2910 ft.

Variably palagonitic volcaniclastic rock. Near-vertical shearing is common. The shearing has distorted much of the original texture of the palagonitic material in many areas. Translucent sheared surfaces have the color of the surrounding rock. Soft, waxy fault gouge is common, though present in variable amounts throughout this zone.

2907 ft.

White zeolite filling of vesicles in basaltic tuff. The vesicles appear to define bedding planes that are on about a 45° angle. Much of the zeolite appears to be acicular. The texture and waxy, sheared surfaces along fractures suggest tectonic deformation.

3288-3290 ft.

Predominantly vertically fractured basalt with light colored clay on fracture surfaces. Tr. native Cu blades occur on the light colored clay.

3291 ft.

Dark gray vesicular basalt. Many of the vesicles are lined and partially filled with olive-green and blue-green clay, occasionally showing horizontal stratification. Occasional vesicles show clear, very fine-crystalline zeolite forming subsequent to the clays. Small, bladed clusters of native copper are observed to form very rarely subsequent to or co-genetic with the zeolite.

3329.5 ft.

Dark gray vesicular basalt. Vesicles are commonly partially to completely filled with very dark gray-green to very light blue-green clay. Vesicles in proximity to vertical fractures are observed to contain cryptocrystalline silica formed subsequent to the clay. Fracture surfaces are commonly coated with a thin film of blue-green to white clay. Minute blades of native copper are observed to form on the clay coatings of the fractures. A late-stage clear precipitate may be a hydrous silica colloid.

The matrix of the basalt has undergone variable amounts of alteration to dark gray-green clay. Many of the mafic microphenocrysts show very little alteration effects.

3399 ft.

Scoriaceous basaltic auto-breccia or agglutinate. Alteration is variable with portions showing extensive clay alteration and other portions showing fresh plagioclase phenocrysts in a glassy matrix. Many vesicles are partially to completely filled with olive-green and light blue-green clays, often overlain with a thin film of very dark gray-green clay. Some vesicles show subsequent precipitation of clear, blocky zeolite which in turn is occasionally followed by sub-mm clear spheres (silica ?).

3481 ft.

Brecciated vesicular basalt. The breccia consists of angular basaltic fragments with very little soft cataclastic slickenside material. The fragment surfaces are coated with a thin film of blue-green clay overlain by clear, blocky zeolite, which in turn is irregularly overlain by clear, botryoidal silica. The zeolite and silica may be cogenetic.

3492-3518 ft.

This zone may represent a lahar or a volcanic debris flow containing large vesicular lapilli and blocks with an ash-rich matrix. The rock is lithified and shows clay alteration. A pervasive greenish color to the rock may indicate a general smectite alteration. The well-site notes mark this as a breccia.

3532-3538 ft.

The rock consists of both primary volcanic breccia, now well lithified, and subsequent tectonic brecciation. Fragments from the tectonic movement show black to green-black, soft, waxy slickenside surfaces. No indication of rock-water interaction or mineral precipitation is evident along the tectonic fractures. Minor light green-gray clay and clear fine-crystalline zeolites are observed lining vesicles in the volcanic fragments.

3579 ft. Sample

Tectonicly brecciated flow rock with both dark and green clay overlain with fine-crystalline zeolites along fracture surfaces.

3579 ft.

Dark gray tectonicly fractured vesicular basalt. The vesicles are commonly filled with olive-green to blue-green clay. The basalt appears to be relatively fresh away from vesicular areas. Near-vertical fractures in the basalt display soft, waxy slickensides with horizontal striations. Open fracture surfaces contain a coating of light blue clay overlain by fine-crystalline, clear zeolite. Occasionaly a later-stage acicular zeolite is observed growing into the open fractures.

3699 ft.

Dark gray scoriaceous basaltic auto-breccia or agglutinate. Abundant small vesicles are filled with olive-green and blue-green clay. Larger vesicles lined with clay show subsequent crystallization of blocky, clear zeolite, followed by sub-millimeter clear spheres (silica ?) and minor acicular zeolite. The groundmass of the basalt shows variable degrees of clay alteration.

3701 ft.

Zeolites have formed in vesicles of what appears to be a volcanic agglutinate-like assemblage. Minor sub-mm blades of native copper are observed to have been formed on the zeolite crystals.

3743-3745.5 ft.

The white mineral noted as possible kaolinite in the well-site logs appears to be a fibrous zeolite. Minor fracture and vesicle lining clays are light green to gray.

4310 ft.

Dark gray vesicular basalt and possible pyroclastic material. Clay alteration of the groundmass is common but variable in intensity. The rock has been tectonicly brecciated. Fracture surfaces are coated with a soft, waxy, dark green to gray-green gouge displaying well defined slickensides. Vesicles in proximity to fractures are lined with a thin coating of green-gray clay, which is in turn overlain with clear, blocky, fine-crystalline zeolites. Gray to blue-gray spherical to botryoidal cryptocrystalline silica locally overlays the zeolite.

3859 ft.

Brecciated volcanics with clay- and silica(?)-lined fractures. Slickensides along fractures are coated with soft, waxy, green to green-gray clays with traces of soft serpentine-like minerals. A fine white mineral coating may be silica. The sample shows no effects of significant rock-water reactions.

3869 ft.

Dark gray microporphyritic pyroxene basalt. Rare traces of a sulfide mineral occurs dispersed throughout the rock. Minor vesicles, generally occurring in clusters, are filled with green-gray clay. The rock groundmass shows moderate ubiquitous clay alteration. Fracturing within this rock tends to be vertically oriented. Fracture filling minerals include an initial thin coating of green-gray clay with possible chlorite, followed by later quartz and chalcedony.

3958-3959 ft.

Basaltic tuff consisting of ash- and lapilli-sized fragments. The groundmass color suggests possible minor palagonite alteration of basaltic glass. Lapilli-sized fragments are very vesicular.

3996 ft.

Dark gray aphanitic basaltic andesite (possibly two-pyroxene?) with minor plagioclase phenocrysts. Sub-mm groundmass plagioclase laths appear to have a sub-parallel orientation. The rock has been fractured and brecciated, with the fracture surfaces displaying a thin coating of soft, occasionally translucent, gouge with well developed slickenside striations. The fracture surfaces are often coated with blue-green and dark green clay, overlain by micro- to crypto-crystalline silica with botryoidal surfaces. The well-site notes describe this as a tectonic breccia.

4081-4089 ft.

Basaltic pyroclastic debris. This may represent an interflow debris zone or a minor tuff horizon. The well-site notes describe this as a volcanic breccia.

4239-4241 ft.

Vesicular basaltic pyroclastic rock. Locally vesicles tend to be flattened. Many of the vesicles tend to be partially filled in a horizontal layering rather than a coating morphology. A common sequence shows basal green clay overlain with clear to white fine-crystalline zeolites. The well-site logs note this area as a volcanic breccia, possibly sulfide bearing. A careful look at only two core fragments failed to show any sulfides.

4240 ft.

Dark gray vesicular basalt. The vesicles are subangular to subrounded and tend to be elongated. Most vesicles are partially to completely filled with clay and zeolite, commonly displaying horizontal stratification within the vesicles. The basal vesicle filling is often a dark gray-green to brown-green clay, overlain by a lighter blue-green clay. Many of the vesicles contain a clear, blocky zeolite as the most recent stage of mineralization. Clay alteration of the rock groundmass is common though irregularly distributed. Fractures in the rock are coated with a soft, waxy gouge, usually no more than a few mm thick, which displays well developed slickensides. Open fractures locally are partially filled with micro- to crypto-crystalline silica and a green clay.

4460-4470 ft.

Vesicular basalt fragments in a finer pyroclastic matrix. The possible flow contact noted in the well-site logs is not very obvious. The degree of general clay alteration within the rock appears to be increasing somewhat from above.

NOTE: The contacts between flows and pyroclastic units are often indistinct and not well noted on the well-site descriptions. Increased lithification of fragmental units with depth tend to obscure the distinctions between agglutinates, autobreccias, pyroclastic units, and volcanic debris (primary and secondary).

4565.5 ft. Sample

Gray to dark gray vesicular microporphyritic basalt with variable clay alteration in the groundmass. The vesicles tend to be elongated with the axes at 35^{o} to 40^{o} to horizontal. Most of the vesicles are partially to completely filled with clay, often displaying a stratified morphology. Other vesicles are lined with blue-green to light blue clay, a dark gray-green clay, and a post-clay clear, blocky, fine-crystalline zeolite. A few of the vesicles contain traces of an acicular zeolite.

4649-4658 ft. (noted as flow with fractures)

Tectonic fractures are common here, often trending toward vertical. The fracture surfaces show well developed slickensides with a soft, waxy surface coating usually no thicker than a few millimeters. Unlike many of the slickensides observed at the shallow and intermediate depths of this hole, these surfaces often show a purple color, likely hematite.

4765.5 ft. Sample

Dark gray microporphyritic basalt with an fresh-appearing aphanitic groundmass with only limited indication of clay alteration. Mottled and irregularly distributed orange staining within the rock suggests some hematite alteration of mafic minerals. The rock is strongly fractured or brecciated. The fracture surfaces are coated with a thin layer of soft, waxy, dark blue-green gouge with slickenside striations. Open fracture areas contain gray-green clay, often overlain with a light gray clay.

Appendix 3. Drill site geologists' report on the shallow geophysical logging run.

To: J. Iovenitti

From: G. Goodwin/A. McDannel

Re: Summary of Field Operations for CTGH-1 Shallow Logging Run

Geophysical borehole surveys were run in CTGH-1 on the morning of June 13, 1986. Surveys were performed by Colorado Well Logging employees Robert E. Crowder, Jr., and Robert E. Crowder, Sr. The surveys prescribed by the CTGH-1 Logging Program (temperature, fluid resistance, sp, 16"-64" resistivity, natural gamma, gamma-gamma density, guard resistivity, caliper), along with a deviation survey and an additional spontaneous potential survey, were completed in five logging runs.

Three maximum recording thermometers (MRT) were run with the logging tool during the first trip. Due to a sustained temperature reversal with depth, an ambient temperature which was greater than downhole temperatures, MRT's were not included in subsequent trips.

The hole was open and unobstructed to its total depth at 517 feet. Hole diameter was 8-3/4 inches. Thirty-five feet of 10-3/4 inch diameter casing was in the top part of the hole. Static water level was 18 feet below ground level.

Trip 1: Temperature and Fluid Resistance (0'-517')

3 Maximum Registering Thermometers (reading 50°, 52°, and 55°F)
06:38 - 07:03 Log on RIH @ 20 fpm
07:03 - 07:11 Stop on bottom
07:11 - 07:20 POH
Comments: MRT results: 1 broken - hit casing shoe @ 35' hard
60°F - casing open to hole fluids
55°F - thermometer isolated from fluids

It was decided not to run MRT's on later trips due to a sustained temperature reversal below a maximum temperature at the top of the hole fluid column.

Trip 2: Spontaneous Potential and 16-64 Resistivity (35'-517')

07:40 - 07:54 RIH to BH
07:54 - 08:15 Logging OOH @ 25 fpm
08:15 - 08:22 RIH to relog 16-64 resistivity without S.P. - potential noise interference between the two instruments
08:22 - 08:40 POH logging 16-64 resistivity only 517'-475', turn on S.P. @ 475' - looks the same as 1st pass (logging rates: 517'-450'@ 25 fpm, 450'-35' @ 30 fmp)

Trip 3: Spontaneous Potential, Single Point Resistivity, and Deviation Tool (35' - 517')

09:02 - 09:10 RIH to BH
09:10 - 09:30 POH logging @ 25 fpm

Comments: Using new S. P. tool (Trip 2 tool appeared to drift but Trip 3 S. P. had similar response: noisy, flat, drifting). No Single Point Resistivity record (maximum deflection for tool is 1,000 ohmmeter and formation resistivity is 1,000 ohmmeter). Using 20°E declination with Deviation Tool.

Trip 4: Natural Gamma (0' - 514') and Guard Resistivity (18' - 514')

09:50 - 10:00 RIH to BH
10:00 - 10:22 POH, logging @ 25 fpm
10:22 - 10:25 RIH to 150' to check for repeatability
10:25 - 10:30 Relogging 150' to surface @ 25 fpm (same response)

Comments: Sampling analog record at 0.5 spacing for digital record of log.

Trip 5: Caliper and Gamma-Gamma Density (35'-517')

10:30 - 11:05 Calibrating both tools
11:05 - 11:15 RIH to BH
11:15 - 11:40 POH, logging @ 20 fpm

Comments: Caliper malfunctioning, readings systematically narrower than hole by 2" - 3"

11:40 - 11:53 Recalibrate caliper and RIH to 150'
11:53 - 11:59 POH; relogging hole @ 20 fpm from 150' to 35'

Comments: Good repeatability on both gamma-gamma resistivity and caliper. Caliper scale adjusted to accurately reflect hole diameter. Digital record again sampled at 0.5' spacing.

11:59 - 12:15 Recalibrate gamma-gamma resistivity tool
12:15 - 12:30 Logging operations complete. Rig down and mob to Detroit to copy field logs.

Appendix 4. COLOG, Inc.'s report on the shallow geophysical logging run.

COLOG INC.

d.b.a. COLORADO WELL LOGGING

1019-8th ST., SUITE 306 • GOLDEN, CO 80401 • (303) 279-0171 • TELEX: 45-0286

June 23, 1986

Mr. Joe Iovenitti
Thermal Power Co.
Suite 120
3333 Mendocino Avenue
Santa Rosa, CA 95401

Re: Borehole Geophysical Logging for Clackamas Geothermal Well-Shallow Logging Run.

Dear Joe,

The following letter serves as a report on the shallow logging run for Thermal Power's Clackamas Geothermal Well recorded June 13th, 1986.

The Clackamas Geothermal Well was drilled to 517 feet at 8 3/4 inches and was then logged before running 7" casing and begining core drilling. The logging suite consisted of Temperature, Fluid Resistivity, Gamma, Guard Resistivity, Dual G-G Density, Caliper, 16-64" (short and long) Normal Resistivity, Spontaneous Potential, and Deviation. Drilling was completed June 12th, 1986 and the well had not been circulated for 14.5 hours prior to logging.

The initial logging run consisted of Temperature and Fluid Resistivity. This probe was recorded from the surface (measured at ground level) downward. The temperature log was recorded at a very sensitive scale - 2.0 degrees Kelvin full scale (273 degrees Kelvin = zero degrees Celcius) to help identify near surface hydrologic effects. Depth was set to the temperature log, the fluid resistivity log was offset slightly due to recorder pen configuration. Key points on the temperature log include overall cooling with depth - the bottom hole temperature was 282 degrees Kelvin (9 degrees C, 48 degrees F) versus a fluid temperature at 18 feet (fluid level) of 289 degrees Kelvin. There was a major cooling zone, 3 degrees K, at 130-135 feet. This is indicative of a significant fracture zone. The temperature gradient from 30 to 126 feet and 444 to 490 feet are nearly the same - rapid cooling with depth. The zone from 126 to 355 feet shows significant temperature changes foot by foot, including the zone at 130-135 discussed earlier and a zone from 200-298 which warmed slightly.

The fluid resistivity was approximately 19-20 ohm-M except for the zone at 130 feet in which the fluid resistivity increased to 23 ohm-M. This indicates that this zone was making fresh water.

The second logging run in the well recorded Spontaneous Potential and 16-64" normal resistivity. The depth was set with respect to the 16" normal resistivity log and the other logs were offset slightly due to recorder pen configuration. The initial logging run showed resistivities from 300 to 7000 ohm-M. The log appears to have some high frequency noise superimposed on top of the log response. This noise is a result of the very high resistivity scale used. The SP log also showed what appeared to be noise. The SP and 16-64" logs were repeated to verify the data. The SP log was repeated with a different probe, module, and surface electrode. Therefore, I have a high degree of confidence that the log is valid. Considering that the fresh water (low TDS) used was also the same type of water encountered in the borehole and the unaltered andesidic formations drilled, this SP response is not unusual.

With the rerun of the SP log, a single point resistance log was attempted. However, the formation resistivity was too high and this log could not be recorded. It has a maximum full scale of 1000 ohms with up to 1000 ohms displacement.

A deviation survey was recorded with the rerun of the SP log. This log was run at this time because the deviation can not accurately be made through steel casing. Steel casing has an artificial magnetic field that distorts apparent tool orientation. Digital inclination and orientation readings were made every 10 feet. The borehole was near vertical at the top of the well and from 290-430 feet. There was a small (up to 1.5 degree) inclination to the north from 80-290 feet and an inclination to the south below 430 feet. The bottom 20 feet are inclined up to 2.6 degrees. A magnetic declination of minus 20 degrees East was used for the deviation survey.

The next logging run recorded gamma ray and guard resistivity both digitally and analog. The gamma log was uneventfull and repeatible. The gamma log was also the basis for depth calculation. The guard resistivity log showed the same basic signatures as the normal resistivity log but at much lower resistivity values. This is a result of tool design. Highly resistive formations require more power to focus the current at depth. In this case, the tool was seeing very shallow effects of the borehole wall. It is valuable to more accurately pick bed boundaries, but doesn't approximate formation resistivity.

The last logging run recorded dual G-G density and caliper. This log was also simultaneously recorded in both digital and analog format. There was a mistake in recording the analog caliper calibration initially, but was detected during logging and upon post-logging calibration. A repeat section was made and the calibration repeated. The digital data was not effected by this mistake. The only effect of this is that the caliper log doesn't fall exactly on even lines; e.g. 4" is not on the 4th line of the paper.

The dual density data shows lower density (higher apparent porosity) to the right. The depth was set to the long spaced G-G detector. On the analog, the short (near) spaced G-G log is offset downward because of recorder pen configuration. The short spaced G-G log also goes off scale frequently on the analog. It was recorded only to help correlate formation breaks and validate the long density log. It should be noted that the lower density zones were frequently associated with small washouts and significant borehole rugosity.

The following steps will be made to this data for the final report:

1. Attempt to correct the normal resistivity data for borehole fluid resistivity and better approximate formation resistivity.

2. Digitize the analog data not recorded digitally in the field. Replot this data corrected for probe offset.

3. Compensate the dual density data.

4. Make a plan and profile view plot of the deviation data.

5. Integrate this log data with data from the next logging phases.

It is anticipated that most of the processing of this data will be done shortly. I am forwarding several copies of the final analog prints recorded in the field. I will also forward copies of the initial processed logs. If you have any questions about this letter or the data, please call.

Sincerely,

Robert E. Crowder
President

thermall.rep

Appendix 5. COLOG, Inc.'s report on the deep geophysical logging operation.

COLOG INC.

d.b.a. COLORADO WELL LOGGING

1019-8th ST., SUITE 306 • GOLDEN, CO 80401 • (303) 279-0171 • TELEX: 45-0286

September 25, 1986

Mr. Joe Ioveniti
Thermal Power Co.
Suite 120
3333 Mendocino Avenue
Santa Rosa, CA 95401

Re: Borehole Geophysical Logging for Clackamas Geothermal Test Well No. 1, September 3-5, 1986.

Dear Joe,

The following letter serves as a report on the final logging program for Thermal Power's Clackamas Geothermal Test Well recorded September 3-5, 1986. I've also attached the original analog data in final form for both logging trips, a copy of the deviation data, and a tabular printout of the digitized log values including the temperature in degrees F.

Colog mobilized September 1-3 to the Clackamas job site and was on site ready to start the logging operations at noon, Sept. 3rd. HQ drilling pipe had parted and was left in the well as casing from approx. 830-4200 ft. HQ casing had been run back down to 830 ft. and the well then drilled from 4200 ft. to approximately 4800 ft. The drilling crew had run NX drill pipe into the well to T.D. and had started circulating (pumping cool water down the well; it did not return to the surface.) prior to Colog's arrival on-site. The drill pipe was pulled from the well and a MRT survey was recorded by the drillers prior to Colog starting logging operations. This MRT survey indicated that the well had been cooled to 153 degrees F, a level acceptable by Colog's downhole probes.

At 23:30 Colog started to rig up and then preceded to run the dual G-G density and caliper log in the well. The dual G-G function on the logging probe failed due to excessive borehole temperature before a density log could be obtained on the open portion of the drill hole (4200-4800 ft.). A caliper log was obtained in this portion of the well, and both caliper and density logs were recorded inside the drill pipe from 900 to 775 ft. These logs were recorded through this interval of drill pipe to investigate the area in which the HQ drill rods had parted at 830 ft. No gaps were apparent on the caliper log. It is possible from the density logs that the joint may be slightly thicker i.e. there is an overlap at the joint that shows as apparent higher density. This probe was out of the drill hole at 03:30 and the three MRT's on the cable immediately above the probe showed 184,188, and 217 degrees F. These temperatures all greatly exceed the dual density tool manufacturer's temperature rating of approx. 150 degrees F. Apparently the borehole temperature rebounded rapidly.

Colog next attempted the full-wave form sonic log. The probe centralizers had to be removed to get the tool down the HX (pipe ID - 3.5", tool OD 2.60") drill pipe because of the grease on the inside of the pipe. Sonic data was recorded going downward from 4225 to 4425'. The tool then failed due to the excessive borehole temperatures. Because of the way the tool failed, the digital full wave form data was lost, and only the analog Delta T and Amplitude data was salvaged. The Delta T data showed formation values of 50 to 100 micro sec./ft. (20,000 to 10,000 ft./sec.). The 100 micro sec./ft. occurred at 4320 ft. and is indicative of high porosity. Numerous cycle skips probably are indicative of fractures in the formation and should be correlated with the core.

Colog next attempted to record the 16-64" resistivity and SP logs. This data could not be collected, because of an apparent short that had developed in the cable. A 6 ft. lateral resistivity and SP log were recorded with this same probe. However, because of the problems demonstrated on the normal resistivity logs this data is questionable. Colog was out of the well at 11:30 and the drillers immediately started to 'trip' the NX pipe back into the well and cool the well. A short in the logging cable was found and repaired. No prints of these logs have been provided.

Cool water was pumped down the well bore for approximately 10 hours and the NX pipe was left in the well to T.D. At 23:30, Colog attempted the gamma-neutron log. This probe was lowered to the bottom of the well as fast as possible and then logged upwards. The probe failed because of the excessive borehole temperatures after logging from 4800 to 4650 feet. The gamma function never completely failed but, is very questionable from 4450 to approx. 4100 feet. The neutron log was totally dead from 4650 to 4520 feet and partially functional to 4100 feet. Data was recorded up to 3500 feet and then the probe was lowered back down to 3950 feet. It was then logged downward until it failed because of the borehole temperature at 4466 feet. The probe was then brought back to 3500 feet and logged out to the surface. At approximately 3000 feet, the gamma function died off to zero. The tool was turned off and initialized again and the gamma function started working. The logs were repeated over the questioned area and then logged to the surface. It is not known why the gamma function died at this point, however, it may have been a result of the high temperatures at depth. A composite gamma-neutron log is attached to this report. Baseline shifts occur in both the gamma and neutron logs where the hole diameter and casing changes. For example, at 4200 ft. the hole diameter decreases form approx. 3.5" to 3" and the neutron log is shifted to the right (less water effect because of smaller borehole - therefore greater count rate). The gamma log also shifts to the right at this point because it is no longer looking through two layers of casing; the NX and the HX. These same type changes also occur at the bottom of the surface casing.

A deviation log was to be the next log recorded in the well. However, a problem developed with the module and the temperature and fluid resistivity logs were recorded while a loose connection on the deviation module was repaired. The temperature and fluid resistivity logs were recorded downward to 4875 feet through the drill pipe. The maximum bottom hole temperature was 361 degrees Kelvin (88 degrees C or 190 degrees F). The temperature log showed only small changes including a cooling trend down to approximately 750 feet with gradual warming to depth. There were several zones that had significantly different temperature gradients including 860-1060 feet in which there was only a very slight increase in borehole temperature. The fluid resistivity log showed an apparent decrease in water quality with depth. From approx. 40 ohm-m at the surface to 9 ohm-m at the bottom of the well. This shift is almost entirely a function of the increase in borehole temperature. A copy of a calibration curve for the Fluid resistivity measurement (in tap water) versus temperature is attached. I have very limited experience with MRT surveys and based upon the variation between the apparent temperatures that were read with the three different MRTs used each time, I question their accuracy to greater than 10%. I have more experience with calibration of Colog's temperature tool and believe it to be accurate to within 1%.

The deviation log was recorded after the T,FR logs by logging downward through the drill pipe at 25 foot intervals. The directional deviation data is erroneous because of the steel casing and pipe in the well bore. The steel casing and pipe is randomly magnetized and the direction Colog's tool measures is magnetically based. It is obvious when the direction changes 180 degrees in 25 feet and the angle doesn't change that the steel is influencing the readings. The steel pipe doesn't effect the vertical angle reading. Overall, this was a very straight borehole.

Upon completion of the deviation survey, 600 feet of drill pipe was then pulled out of the well leaving the bottom 4200-4800 feet open. The 16-64" normal resistivities, SP, IP, and a 6 ft. lateral resistivity were recorded in this portion of the well. All of the resistivity data was consistent between the different types of measurements and the pre and post logging calibrations checks were the same. Additionally, Colog's equipment manufacture specifies that the 16" short normal resistivity log should indicate approx. 5.1 ohm-m for every ohm of load used in calibration, and the 64" long normal resistivity should indicate approximately 20 ohm-M for every ohm of load. This is consistent with the field calibration checks. The small variation between actual and theoretical resistivities is due to the cable length, variation within the load resistors (nominal 10% resistors), and contact resistance. Therefore, I believe the tool to be working correctly and the data to be valid. Please note that the previous 6 foot lateral resistivity and SP data showed the same shape of curve, however, the logging scales were substantially different. I don't believe the original 6 foot lateral quantitative data to be valid because of the cable problems that were found after it was recorded.

It is somewhat disconcerting to see resistivity values in the 4 to 10 ohm-M range. The core samples were altered however, the neutron data indicates that the formation has very low hydrogen content (no water) and these resistivity values seem unrealistically low. The 9 ohm-M borehole fluid values would mean that apparent formation resistivity values of 9 ohm-M would indicate 100% porosity. For the apparent formation resistivity to be less than this value, the formation needs to be more conductive than the borehole fluid, i.e. contain saline formation water, disseminated sulfide, or some other conductive material.

The neutron logs suggest that there is very little formation water available. The slower sonic delta T's correspond to the lower resistivity values and also indicate higher porosity. Therefore, I am inclined to believe the porosity is dry. G-G density data in this area would have been very beneficial. The increase in borehole temperature will decrease the apparent resistivity some, however, I don't believe it would be significant enough to cause these extremely low values. At best, I think that the temperature correction would only increase these values by 20-25 ohm-M. One temperature correction formula for normal resistivity logs was obtained from literature and states that $R1(T1+7) = R2(T2+7)$ with the temperature in degrees F. Five ohm-M at 200 degrees F would equal approx. 20 ohm-M at 50 degrees F with this formula. I haven't seen enough information to know the limits, if any, for this formula. More investigation, including some core resistivity measurements, needs to be made to explain this result. It should be noted that the higher resistivity layers correspond to the higher (lower apparent porosity) neutron values and faster sonic velocity values, which is consistent.

The gamma, neutron, dual G-G density, caliper, and sonic logs were simultaneously recorded in digital and analog format. The digital sonic data was lost when the tool failed from the temperature. This was a very different shut-down than the up-hole logging equipment was designed for. The deviation data was also recorded digitally. The temperature, fluid resistivity, 16-64" normal resistivity, 6 ft. lateral resistivity, spontaneous potential, and induced potential logs were record only in analog form and then digitized.

The logging program for the well was effected by the overall borehole conditions. Significant data was not obtainable after the HQ drill pipe was parted and left in the well. This includes continuous resistivities from the surface to the bottom interval, density, and sonic data. Density and complete sonic, gamma, and neutron data could not be collected in the open portion of the well (4200-4800 ft.) because of the borehole temperatures. The temperature in this drill hole rebounded very rapidly after the cooling attempts.

A major conclusion does seem to be apparent from the well log data collected. The well below 2000 feet appears to have a very low porosity, little permeability, and low potential as a natural geothermal aquifer. This is demonstrated by the lack of thermal gradient changes in the temperature log (which indicates lack of aquifer systems in this area), the overall low formation temperature, the high neutron count values (indicative of low formation water), and the lack of SP change which suggests little permeability. The low resistivity values are consistent with major clay alteration which would further reduce any permeability, however, they still need more explanation. They don't seem realistic with the known core and neutron values.

It was not practical to link the logging data from the first trip with these last logs primarily because of the lack of data that could be collected through the cased portion of the well. I will work with this data in more detail when I receive additional information, including a comprehensive geologic description, and ideally some resistivity and porosity values from the core and/or several pieces of the cores that we could test.

If you have any questions about this report or some additional information, please call.

Thanks again,

Robert E. Crowder
President / Geophysicist

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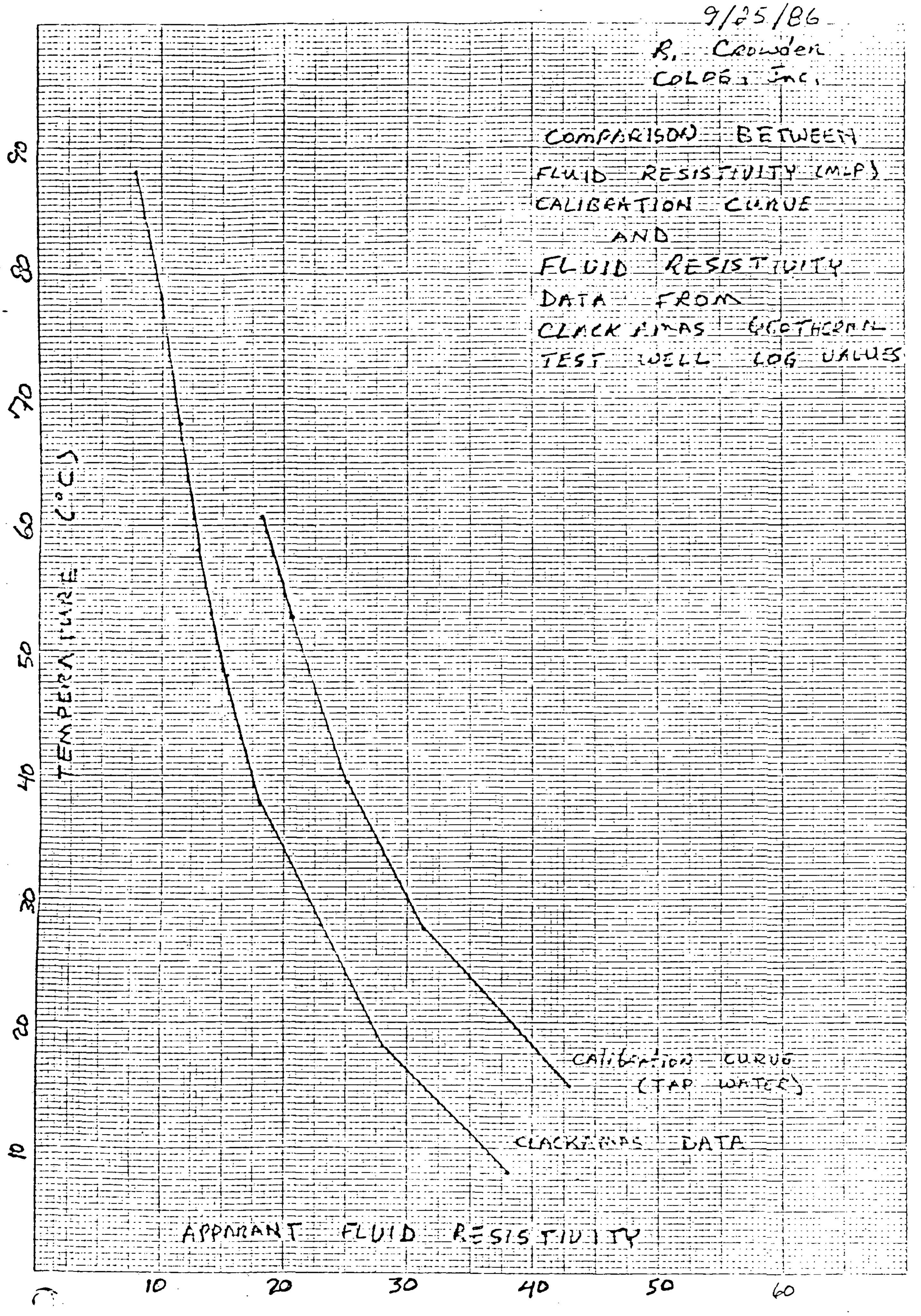
9/25/86
R. Crowder
COLOG, Inc.
COMPARISON BETWEEN
FLUID RESISTIVITY (M-P) CALIBRATION CURVE
AND
FLUID RESISTIVITY DATA FROM CLACKAMAS GEOTHERMAL TEST WELL LOG VALUES
TEMPERATURE (°C)
90
80
70
60
50
40
30
20
10
CALIBRATION CURVE (TAP WATER)
CLACKAMAS DATA
APPARANT FLUID RESISTIVITY
10
20
30
40
50
60