MASTER

**INTERPRETATION OF
WELL LOG DATA FROM FOUR DRILL HOLES AT
ROOSEVELT HOT SPRINGS KGRA**

W. E. Glenn

J. B. Hulen

December, 1979

Work performed under Contract No. EG-78-C-07-1701

EARTH SCIENCE LABORATORY
University of Utah Research Institute
Salt Lake City, Utah

Prepared for
U.S. Department of Energy
Division of Geothermal Energy

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

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

MASTER

**INTERPRETATION OF
WELL LOG DATA FROM FOUR DRILL HOLES AT
ROOSEVELT HOT SPRINGS KGRA**

by

W. E. Glenn

J. B. Hulen

December, 1979

DISCLAIMER

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

**EARTH SCIENCE LABORATORY
UNIVERSITY OF UTAH RESEARCH INSTITUTE
420 Chipeta Way, Suite 120
Salt Lake City, Utah 84108**

**Prepared for
THE DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY
Under Contract No. EG-78-C-07-1701**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

NOTICE

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

NOTICE

Reference to a company or product name does not imply approval or recommendation of the product by the University of Utah Research Institute or the U.S. Department of Energy to the exclusion of others that may be suitable.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	1
INTRODUCTION	3
GEOLOGICAL AND GEOPHYSICAL SETTING OF THE ROOSEVELT HOT SPRINGS KGRA .	4
LITHOLOGY AND ALTERATION, UTAH STATE DRILL HOLES 52-21, 14-2, and 72-16, and THERMAL GRADIENT HOLE GPC 15 -- GENERAL STATEMENT	7
DISCUSSION OF WELL LOG DATA	9
DISCUSSION OF WELL LOG DATA FOR UTAH STATE DRILL HOLE 52-21	9
Drill Hole Location and Drilling History	9
Geologic Log	10
Well Logs	12
Drilling Rate	12
Temperature Logs	12
Caliper Log	16
Interval Transit Time (Velocity) Log	16
Neutron Porosity Log	17
Bulk Density Porosity Log	17
Bulk Density Log	18
Resistivity Log	18
Spontaneous Potential Log	19
Natural Gamma Log	19
DISCUSSION OF WELL LOG DATA FOR UTAH STATE DRILL HOLE 14-2	21
Drill Hole Location and Drilling History	21
Geologic Log	21
Well Logs	22
Temperature Logs	24
Caliper Log	25
Interval Transit Time (Velocity) Log	25
Neutron Porosity Log	26
Density Porosity/Bulk Density Log	26
Resistivity Log	27
Spontaneous Potential Log	27
Natural Gamma Log	28
DISCUSSION OF WELL LOG DATA FOR UTAH STATE DRILL HOLE 72-16	29
Drill Hole Location and Drilling History	29
Geologic Log	30
Well Logs	31
Drilling Rate	31
Temperature Logs	33
Cement Bond Log	36
Natural Gamma Log	37

	<u>Page</u>
DISCUSSION OF WELL LOG DATA FROM THERMAL GRADIENT HOLE GPC-15.	38
Drill Hole Location and Drilling History	38
Geologic Log	38
Well Logs	39
Temperature Logs	39
Caliper Logs	41
Interval Transit Time (Velocity) Log	41
Bulk Density Log	43
Resistivity Log	44
Spontaneous Potential Log	44
Natural Gamma Log	44
ESTIMATE OF ROCK PROPERTIES FROM WELL LOGS	45
Alluvium	46
Igneous and Metamorphic Rocks	52
HEAT FLOW AND FLUID ENTRIES IN UTAH STATE 52-21, 14-2, 72-16, and GPC-15	62
SUMMARY	68
ACKNOWLEDGEMENTS	71
REFERENCES	72

LIST OF TABLES

Table 1:	Well logs obtained in Utah State Drill Hole 52-21, Roosevelt Hot Springs KGRA	13
Table 2:	Well logs obtained in Utah State Drill Hole 14-2, Roosevelt Hot Springs KGRA	23
Table 3:	Well logs obtained in Utah State Drill Hole 72-16, Roosevelt Hot Springs KGRA	32
Table 4:	Well logs obtained in Thermal Gradient Drill Hole, GPC-15, Roosevelt Hot Springs KGRA	40
Table 5:	Summary of bulk density-interval transit time crossplot interpretations, GPC-15	51
Table 6:	Summary of acoustic velocity, bulk density, neutron porosity and electrical conductivity in Utah State geothermal wells 14-2 and 52-21	54
Table 7:	Selected mineralogy of ten-foot chip samples in drill hole 52-21, between 5190 and 5310 feet (1583-1620m)	59

	<u>Page</u>
Table 8: Estimate of potential permeable zones in the four holes based on log data	69

LIST OF FIGURES

Figure 1	Location Map	5
Figure 2	Generalized geology and selected geothermal well locations	6
Figure 3	Drill hole survey plot for Utah State 52-21 below 2041 feet (622m)	11
Figure 4	Temperature gradient in Utah State 52-21	15
Figure 5	Temperature gradient in Utah State 72-16	35
Figure 6	Temperature gradient in GPC-15	42
Figure 7	Crossplots of interval transit time and bulk density for the interval 558 to 1898 feet (170-579m) in GPC-15 . .	48
Figure 8	Loop from Utah State Geothermal Well 52-21	55
Figure 9	Neutron porosity - bulk density crossplot for Utah State Geothermal Well 52-21, 5190 to 5310 feet (1583-1620m).	57
Figure 10	Plot of volume percent mafic minerals versus neutron, density and velocity logs for interval 5190 to 530 feet (1583-1620m) in Utah State Geothermal Well 52-21 . . .	58
Figure 11	Thermal conductivity as a function of temperature for several rocks (after Clark Jr., 1966)	63

LIST OF PLATES

Plate I	Log composite of Utah State Geothermal Well 52-21 . . . . in pocket
Plate II	Log composite of Utah State Geothermal Well 14-2 . . . . in pocket
Plate III	Log composite of Utah State Geothermal Well 72-16 . . . . in pocket
Plate IV	Log composite of GPC-15 . . . . . in pocket

ABSTRACT

Well logs from four drill holes, Utah State Geothermal Wells 14-2, 52-21 and 72-16 and Geothermal Power Corporation's thermal gradient hole GPC-15 have been digitized, plotted and studied. This study had three objectives: 1) to present the well log data in a convenient format for easy study, 2) to determine the nature of the geothermal reservoir rock and fluid properties, and 3) to make some inference on fluid entry locations in the boreholes and their effect on heat flow.

The alluvium, which varies in thickness from 160 feet (49 m) at 72-16 to over 1900 feet (580 m, TD) at GPC-15, exhibits compaction and cementation with depth. Bulk density increases and porosity decreases with depth, from 2.28 to 2.46 gm/cc and from 23% to 15%, respectively, between 558 and 1898 feet (170-579 m), which is below the interpreted water table at 540 feet (165 m). Over the same interval, the acoustic velocity increases from 8200 ft/sec (2.5 km/sec) to about 14,000 ft/sec (4.3 km/sec) at the bottom of the hole. Above the water table the bulk density varies considerably, but averages approximately 2.05 gm/cc.

Bedrock in Utah State 14-2 and 52-21, various granitic intrusives and mafic to granitic gneisses, exhibits highly variable log properties throughout the length of the holes. The log responses have been interpreted in terms of lithologic effects peculiar to igneous and metamorphic rocks. Dense, hydrous-mafic mineral contributions can be identified in acoustic, density and neutron logs. Acoustic velocities vary between 15,500 and 22,000 ft/sec (4.7 and 6.7 km/sec). Bulk densities vary between 2.5 and 2.8 gm/cc; resistivities

vary from 40 to greater than 2000 ohm-m, and neutron porosities vary between nearly zero to 15%. Lower velocity, density and resistivity and higher neutron porosity are fracture-related values and occur above 2000 to 3000 feet (610-915 m) in both holes. Potentially permeable and possibly related production zones correspond to these log responses, correlate with fractures, and occur primarily in the upper levels of each hole. However, permeability in 52-21 is quite low and the hole is considered a non-producer.

The temperature logs and gradients computed from these logs have been used to examine heat flow in the vicinity of the four drill holes. Assumed and calculated thermal conductivities have been used in the analyses, 4 mcal/cm °C sec for the alluvium and 7 mcal/cm °C sec for the crystalline rocks. The data indicate that 14-2 and 72-16 reside in a dominantly convective heat flow environment, whereas GPC-15 and 52-21 reside in a dominantly conductive heat flow environment. The convective regions are believed to be fracture controlled and only portions of each hole reside totally in a convective region; in each case it is the upper bedrock portion of the hole. In every case the alluvium or upper portion of the alluvium acts as a thermal blanket over the system. Maximum heat flow among the holes, 40 μ cal/cm² sec, occurs in the vicinity of 72-16 and the lowest heat flow, 4 μ cal/cm² sec, in the vicinity of GPC-15.

INTRODUCTION

Well logs from four drill holes (Utah State 52-21, 14-2 and 72-16, and thermal gradient hole GPC-15) have been submitted to the University of Utah Research Institute, Earth Science Laboratory by Getty Oil Company, Thermal Power Company, and Geothermal Power Company as part of their data packages due under terms of participation in the DOE/DGE Industry Coupled Program. Most of the well logs have been digitized, plotted, and studied. Reproductions of the original logs can be obtained from Rocky Mountain Well Log Services, Denver, Colorado.

This report has three objectives: 1) to present the well log data in a convenient format which permits interested individuals to evaluate directly and interpret the logs, 2) to determine the nature of the geothermal reservoir rock and fluid properties, and 3) to make some inference about fluid entry locations in the boreholes and about heat flow.

The first part of the report will simply describe the data and the presentation format. The second part will discuss some interpretations of the well log data that have been completed to date. Lithologic logs, from a study of chip samples, have been included and some correlation between the lithology and various well logs has been made. An attempt has been made, using the log data, to determine fluid entry points in the drill holes.

GEOLOGICAL AND GEOPHYSICAL SETTING OF THE ROOSEVELT HOT SPRINGS KGRA

The Roosevelt Hot Springs KGRA has been recently mapped and studied in detail by Nielson and others (1978). Most of the following has been summarized from their report, to which the interested reader is referred for more detailed information.

The KGRA is situated on the west-central flank of the Mineral Mountains (Figure 1), the easternmost fault-block range at this latitude in the Basin and Range Province. The oldest rocks exposed within the KGRA are Precambrian amphibolite-grade gneisses. These gneisses are intruded by various granitic phases of the Tertiary Mineral Mountains pluton, in turn intruded by later Tertiary microdiorite, diabase, and rhyolite plugs and dikes. Intrusive activity at Roosevelt terminated with emplacement of rhyolite domes, flows, and tuffs between 0.8 and 0.5 m.y. ago. Detritus derived from the rhyolites and older rocks in the range forms a thick alluvial wedge in the valley, over the western half of the KGRA.

Geothermal waters at Roosevelt circulate in a structurally controlled reservoir developed through interaction of four major fault systems. Chief among these, in terms of controlling fluid flow, are thought to be low-angle, west-dipping denudation faults, associated high-angle northwest-trending faults, and northerly trending high-angle Basin and Range normal faults.

Surface hydrothermal alteration within the KGRA is dominated by the siliceous sinter and associated altered and cemented alluvium found along and north of the northerly trending Opal Mound Fault (Figure 2). Bedrock in the area is only locally and generally only weakly altered.

Figure 1
LOCATION MAP

◦ SALT LAKE CITY

◦ PROVO

◦ RICHFIELD

MILFORD ◦

**ROOSEVELT
HOT SPRINGS
KGRA**

◦ ST. GEORGE

FIGURE 2 **GENERALIZED GEOLOGY** **&** **SELECTED GEOTHERMAL** **WELL LOCATIONS**

Roosevelt Hot Springs KGRA
 and vicinity
 Beaver County, Utah

EXPLANATION

• 72-16 Geothermal Well Location

- Quaternary hot spring deposits and related hydrothermal alteration
- Quaternary alluvium
- Quaternary basalt and basaltic andesite
- Quaternary rhyolite domes, flows and tuffs, undivided
- Tertiary Sevier River Formation terrigenous clastic sedimentary rocks, lacustrine marls and subordinate limestone
- Tertiary rhyolite (extrusive)
- Tertiary rhyolite porphyry (intrusive)
- Tertiary granite, fine-crystalline; "fine-grained granite" (Tgr) *
- Tertiary granitic rock, undivided
- Permian Kaibab Limestone
- Permian Coconino Sandstone
- Precambrian biotite-hornblende quartz monzonite gneiss; "hornblende gneiss" (PCgn) *
- Precambrian feldspar-quartz-biotite (± hornblende, ± sillimanite) gneiss; "banded gneiss" (PCbg) and "biotite gneiss" (PCn) undivided *
- Fault, approximately located
- Photo-linear in Qal; probable fault

* Nielson and others (1978)

Mylonite zones formed along low-angle denudation faults and associated high-angle faults are commonly strongly silicified and propylitized. Much of the bedrock alteration at Roosevelt almost certainly predates the presently active geothermal system (Hulen, 1978; Nielson et al., 1978).

Utah State geothermal wells 14-2 and 72-16, both production wells, are collared within a favorable zone of anomalous geophysical response defined by low subsurface resistivity and high thermal gradient (Ward and Sill, 1976; Sill and Bodell, 1977). Getty Oil Company's Utah State 52-21, a non-producer, and Geothermal Power Corporation's thermal gradient hole GPC-15 are collared, respectively, just south and southwest of this favorable zone. Drill hole locations are shown in Figure 2.

LITHOLOGY AND ALTERATION, UTAH STATE DRILL HOLES 52-21, 14-2 and 72-16,
and THERMAL GRADIENT HOLE GPC-15

GENERAL STATEMENT

Lithologies penetrated by the subject drill holes can be tentatively assigned to surface rock types mapped within and near the Roosevelt Hot Springs KGRA by Nielson and others (1978). Correlation is based primarily upon comparison of chip samples from the holes with outcrop samples crushed to simulate drill cuttings. For lithologic descriptions of the individual drill holes, the reader is referred to later sections of this report.

Loosely-cemented microbreccia and gouge chips, many of which are slickensided, are ubiquitously distributed in bedrock cuttings from the drill holes. These chips are particularly abundant in Utah State 52-21 (Plate I).

Many of these chips are probably derived from fault zones. Some, however, may be produced artificially during the drilling process.

Bedrock encountered in the subject drill holes is pervasively, though generally weakly, hydrothermally altered. The alteration is characterized by partial replacement and microveining of host lithologies with various combinations of the minerals chlorite, calcite, quartz, sericite, epidote, leucoxene, and hematite with scattered traces of anhydrite and secondary potassium feldspar. Montmorillonite and mixed layer clays are locally present, particularly in the upper portions of the holes (Nielson and others, 1978; Ballantyne and Parry, 1978; Rohrs and Parry, 1978; Ballantyne, 1978). These alteration minerals are commonly accompanied by minor pyrite with local traces of chalcopyrite. Earthy iron oxides in the upper portions of the holes were probably formed through oxidation of these sulfides. Bedrock sulfide mineralization is conspicuously concentrated within (although not confined to) zones of microdiorite dike intrusion in 14-2 and 52-21.

Post-depositional alteration of alluvium in the four drill holes, except below 300 feet in 72-16, is confined to minor carbonate cementation. Alluvial grains, however, commonly show evidence of pre-depositional alteration (Hulen, 1978, p. 9; Nielson and others, 1978, p. 37). Two horizons below 300 feet in the alluvium of 72-16 are intensely silicified and weakly pyritized (Rohrs and Parry, 1978, p. 3,4 and Fig. 1; Nielson and others, 1978, p. 37 and Appendix 1).

DISCUSSION OF WELL LOG DATA

Various well logs have been released for drill hole 52-21 by Getty Oil Company, for drill holes 14-2 and 72-16 by Thermal Power Company, and for drill hole GPC-15 by Geothermal Power Company. Copies of these logs can be obtained from Rocky Mountain Well Log Service, Denver, Colorado. Obviously, these logs were obtained to satisfy each company's program objectives and all the data available to the companies, of which the well logs are an integral part, are not available to the authors. Hence, an exhaustive study of the logs at this time is impossible. The list of available well logs for each hole and some comment on the quality or significance of each log is given below. A later section will describe some log interpretations.

DISCUSSION OF WELL LOG DATA FOR UTAH STATE DRILL HOLE 52-21

Drill Hole Location and Drilling History

Utah State Geothermal Well 52-21 is located 2310 feet (705 m) west and 990 feet (302 m) south of the north-east corner of Sec. 21, T27S, R9W, Beaver County, Utah. The well was drilled by Coastal Drilling Company for Getty Oil Company. Drilling began on 2/2/78 and was completed on 5/4/78. The hole was drilled entirely with mud.

R. F. Smith Corporation provided on-site logging of drilling rate, bulk density, temperature, lithology, and CO₂ content. The drilling rate, bulk density and temperature logs, together with bit sizes, casing installation dates, and a summary of a Getty Oil Company drilling and well completion report, are presented on Plate I.

Getty Oil Company has also supplied a hole deviation computation from a Schlumberger Dip Log (reproduced here in Figure 3). The data begin at a depth of 2041 feet (623 m); hence, the true location of the hole at depth cannot be determined. The data show that the drill hole migrates more than 500 feet (153 m) south and 500 feet (153 m) west between depths of 2041 feet (623 m) and 6252 feet (1907 m). The true vertical depth (ignoring any hole shortening above 2041 feet, 623 m) at a measured depth of 6252 feet (1907 m) is 6088 feet (1857 m).

No lost circulation or fluid inflow zones were reported during drilling of 52-21. The hole has been cased to 2039 feet (623 m) with 9-5/8 inch (24.5 cm) casing. All depths quoted for 52-21, including those used in Plate I, refer to Kelly Bushing (KB) which was 22 feet (6.7 m) above ground level.

Geologic Log

Utah State 52-21 (Plate I) penetrated pumice- and perlite-bearing arkosic alluvium to a depth of 240 feet (73 m), arkosic alluvium to 570 feet (174 m), and primarily a sequence of poorly- to well-foliated amphibolite-grade gneisses to the bottom of the hole at 7500 feet (2288 m). The gneisses have been correlated with the Precambrian banded gneiss (PGbg) and hornblende gneiss (PGgn) exposed at the surface. Leucocratic granitic chips occur in nearly all samples of the banded gneiss in 52-21, and probably represent both granitic metamorphic segregations as well as granitic dikes and sills of Tertiary age. Between 1980 feet (604 m) and 2790 feet (851 m), the gneisses and granites are intruded by numerous dikes and/or sills of biotite hornblende microdiorite and allied dacite porphyry. The microdiorite ("Tmd" of Nielson

(a)

(b)

Figure 3: (a) Horizontal & (b) Vertical Projections of Utah State 52-21 Hole Deviation Below 2041' Depth

and others, 1978) is typically intensely hydrothermally altered and sulfide-bearing; the dacite porphyry is unaltered and unmineralized.

Hydrothermal alteration of bedrock in Utah State 52-21 is very weak overall, but intense in isolated intervals. Microdiorite dikes between 1980 feet (604 m) and 2790 feet (851 m), for example, are commonly strongly altered to calcite-sericite-quartz-chlorite aggregates, and may contain up to 1% disseminated pyrite.

Well Logs

The well logs obtained in Utah State 52-21 and submitted to the Earth Science Laboratory are listed in Table 1 and most are plotted on Plate I. A brief discussion of each log follows.

Drilling Rate: The record of bit penetration rate during drilling is given in Plate I in feet/hour. This rate is dependent upon a number of factors (Cunningham, 1978); among them are weight on the bit, mud weight, type of bit, circulation, bit wear, and rock type. Occasionally, drilling rate increases in fractured rock, which in turn is commonly associated with fluid flow or lost circulation zones. The correlation between fractured rock and increased drilling rates is evident in several intervals in 52-21; for example, the interval 2030 feet to 2250 feet (619-686 m) shows this correlation. The interval between 5400 feet and 5500 feet (1647-1678 m), by contrast, shows no correlation of increased drilling rate with fractured rock.

Temperature Logs: Eight temperature logs were obtained in 52-21 and seven are reproduced in Plate I. The Agnew and Sweet log of 3/5/78 is

Table 1: Well Logs Obtained in Utah State Drill Hole 52-21; Roosevelt Hot Springs, KGRA

<u>Log Type</u>	<u>Date</u>	<u>Logging Co.</u>	<u>Digi- tized</u>	<u>Casing Depth</u>	<u>Logged Footage (FT.)</u>	<u>Fluid Type</u>	<u>Comments</u>
Drilling Rate	2/7 to 4/29/78	R.F. Smith	Yes	--	0-7500	Mud	Logged during drilling
Bulk Density	"	R.F. Smith	Yes	--	0-7500	Mud	Logged during drilling
Temperature	"	R.F. Smith	Yes	--	0-7500	Mud	Logged during drilling
Temperature	2/14/78	Schlumberger	Yes	182	50-768	FGM	Logged 7 hrs. after circulation
Temperature	3/5/78	Schlumberger	Yes	762	48-2049	Fresh Mud	Logged 16 hrs. after circulation
Temperature	3/5/78	Agnew & Sweet	Yes	762	0-2041	NA	Logged 22 hrs. after circulation
Temperature	5/1/78	Schlumberger	Yes	2041	500-7504	Water	Logged 14 hrs. after circulation
Temperature	6/9/78	Pruett	Yes	2041	40-7400	NA	"Static"
Temperature	7/13/78	Pruett	Yes	2041	40-7315	NA	"Static"
Temperature	10/22/78	Pruett	Yes	2041		NA	"Static"
Dual Ind/LL8	2/14/78	Schlumberger	Yes	182	182-765	LIQ	R _m /°F: 5.67/73
Dual Ind/LL8	3/4/78	Schlumberger	Yes	762	762-2045	Fresh Mud	R _m /°F: 2.03/67
Dual Ind/LL8	4/11/78	Schlumberger	Yes	2041	2041-6250	Fresh Mud	R _m /°F: 3.25/70
Dual Ind/LL8	5/1/78	Schlumberger	Yes	2041	6050-7508	Water	R _m /°F: not available
SP	2/14/78	Schlumberger	Yes	182	182-765	LIQ.	
SP	3/4/78	Schlumberger	Yes	762	762-2045	Fresh Mud	
Natural Gamma	4/11/78	Schlumberger	No	2041	2041-6250	Fresh Mud	
Natural Gamma	5/1/78	Schlumberger	No	2041	6050-7508	Water	
Comp. Sonic Log	3/4/78	Schlumberger	Yes	762	760-2038	Fresh Mud	
Comp. Sonic Log	4/12/78	Schlumberger	Yes	2041	2044-6250	Fresh Gel	
Comp. Sonic Log	5/1/78	Schlumberger	Yes	2041	6050-7507	Water	
Natural Gamma	3/4/78	Schlumberger	No	762	760-2038	Fresh Mud	
Natural Gamma	5/1/78	Schlumberger	No	2041	6050-7507	Water	
Comp. Neut.	2/14/78	Schlumberger	Yes	182	183-767	LIQ.	Limestone units
+Density	3/4/78	Schlumberger	Yes	762	762-2048	Fresh Mud	"
+Caliper	4/11/78	Schlumberger	Yes	2041	2043-6254	Fresh Gel	"
+Nat. Gamma	5/1/78	Schlumberger	Yes	2041	6050-7512	Water	"
Frac. I.D. Log	4/1/78	Schlumberger	No	2041	2043-6256	Fresh Mud	
Frac. I.D. Log	5/1/78	Schlumberger	No	2041	6200-7516	Water	
Caliper	4/11/78	Schlumberger	Yes	2041	2043-6256	Fresh Mud	
Natural Gamma	4/11/78	Schlumberger	No	2041	2043-6256	Fresh Mud	

omitted. Note that the first five logs were obtained either during drilling or shortly after circulation of the drill hole. The last three logs, all logged by Pruett Wireline Service, were obtained from one to five months after completion of the drill hole. The three logs exhibit very little change in borehole temperature with time which suggests that the drill hole was nearly recovered to the true geothermal gradient. The slight temperature change observed between each log will be examined in a later section on a study of heat flow. The last temperature log, Pruett Log of 10/22/78, indicates a bottom hole temperature of 402.4°F (205.8°C).

Thermal gradients computed from the 7/13/78 log are plotted in Figure 4.¹ The three curves in Figure 4 represent three different intervals, 25 feet, 50 feet, and 100 feet (7.6, 15.3 and 30.5 m), that were used to compute the temperature gradients. The gradient is high above 280 feet (85 m) and quite variable above 560 feet (171 m), which is the depth of the alluvium. The gradient oscillates about 100 °C/km between 560 and 2150 feet (171-656). Below 2150 feet (656 m) the gradient slowly decreases to a minimum at 4000 feet (1220 m). The gradient then increases to about 150 °C/km at 4850 feet (1479 m) and goes through a reversal to a minimum of about -12 °C/km at 5250 feet (1601 m). The gradient below 5250 feet (1601 m) gradually increases with depth, although it is interrupted by short low-gradient intervals and/or gradient reversals.

---

¹This study was completed before the final log of 10/22/78 was received. Gradients computed from the two logs are not significantly different.)

EXPLANATION

- pumiceous and perlitic arkasic alluvium
- arkasic alluvium
- biotite hornblende microdiorite
- biotite granite and granitic segregations in gneiss, undivided
- biotite hornblende quartz monzonite gneiss
- feldspar-quartz-biotite (± hornblende, ± sillimanite) gneiss

* NOTE: For more detailed explanation, refer to plate I

**EARTH SCIENCE
LABORATORY**

UNIVERSITY of UTAH
RESEARCH INSTITUTE

**TEMPERATURE GRADIENT
IN UTAH STATE 52-21**

COMPUTED FROM PRUETT
LOG OF 7/13/78

Figure 4

The decreasing and variable gradient below 2150 feet (656 m) could be interpreted in several ways (Bodvarsson, 1973). A changing thermal conductivity could change the gradient. Geologic logs of 52-21 (Plate I, Figure 3), however, show no significant changes in lithology with accompanying changes in thermal conductivity. Only thermal conductivity measurements of the rocks would settle this question. Note that the zero cross-overs in the gradient at 5100 and 5400 feet (1556-1647 m) are the maximum and minimum of the temperature reversal. The extreme points at 4850 and 5270 feet (1479-1607 m) are the inflection points in the anomaly. A further discussion of the temperature logs will be given later.

Caliper Log: Two caliper logs are shown in Plate I. The bit size and casing diameter record is included for reference. The caliper logs show an inaccurate borehole diameter, but each log reflects hole diameter variation. These variations are seldom symmetric about the hole; either an independent arm caliper log or more than one standard caliper log would demonstrate this asymmetry. The caliper logs are essential to interpretation of other logs whose responses are sensitive to borehole size.

Caliper logs give qualitative information on the location of fracture intersections in the borehole. For example, the caliper logs indicate that the interval 2030 to 2900 feet (619-885 m) is probably highly fractured. Portions of this interval show drilling rate increases, high neutron and density porosity, lower resistivity, and longer travel times.

Interval Transit Time (Velocity) Log: The interval transit time log is plotted in units of $\mu\text{sec}/\text{ft.}$, which is the usual format for the

acoustic velocity log. The acoustic velocity of the formation is simply the reciprocal of this log. With only local exceptions, the interval transit time averages 55 $\mu\text{sec/ft.}$ between 720 and 1500 feet (220-458 m), 50.5 $\mu\text{sec/ft.}$ between 1500 and 2660 feet (458-811 m), and 45 to 47 $\mu\text{sec/ft.}$ below 2660 feet (811 m). These changes could reflect a decrease in matrix travel time with depth or a decrease in porosity with depth. Velocity should show a small decrease with increasing temperature (Timur, 1976) and this effect is not observed in this log. Small cracks in igneous rocks close with confining pressure which implies a closing of cracks with depth. The result is an increased acoustic velocity with crack closure, hence, an increase in velocity with depth. Locally, the biotite-hornblende, quartz monzonite gneiss correlates with increased velocity (a decrease in travel time).

Neutron Porosity Log: The porosity log is based on limestone calibration. In igneous rocks the apparent porosity can often be attributed to water in hydrous minerals (Nelson and Glenn, 1975) and to open fractures (Glenn and Nelson, 1977). The true pore porosity may be as low as one-half per cent and be completely masked by these other effects. For example, the neutron log in Plate I is dominated by hole rugosity and fractures between 720 and 2900 feet (220-885 m).

Bulk Density Porosity Log: The density porosity log was computed assuming a constant matrix density of 2.71 gm/cc (limestone). This log clearly presents an erratic porosity for 52-21 and it resembles the neutron porosity log only in a few places. We believe this log demonstrates the difficulty in computing porosity from the density log in igneous or meta-

morphic rocks where matrix density variations may be larger than porosity variations. Since porosity is very low and a uniform matrix density is assumed in the porosity computations, the actual matrix density variations produce a false porosity (Glenn and Nelson, 1977). A good example of this effect occurs between 5180 and 5270 feet (1580-1607 m). Large, negative porosities are also typical and can be seen on this log.

Bulk Density Log: Two bulk density logs are shown in Plate I. One is the Schlumberger log from which the porosity log discussed above was computed. The second log was obtained by R. F. Smith Corp. during the drilling operation. The Schlumberger log is influenced by borehole enlargement in many places (see notes on the log), particularly above 1000 feet (305 m). The smoothed bulk density, which may be of interest to geologists and geophysicists, is close to 2.63 gm/cc from 2,000 to 7,500 feet (610-2288 m).

Resistivity Log: The resistivity logs are Schlumberger's Dual Induction-Laterolog combination log: Medium and Deep Induction Logs and Laterolog 8. These logs were obtained on four separate days and mud resistivity was quite different for each run (Table 1). Mud resistivity (R_m) for the final run was not measured but was probably similar to the value measured for run one.

The extremely variable resistivity shown by the three logs is typical of a highly resistive rock disrupted by conductive cracks and/or veins. The degree of coincidence of the three resistivity logs depends upon the crack frequency and electrode separation. Lower resistivities associated with fracturing are evident throughout the log, for example, between 2020 and 2900 feet (616-885 m) and between 3400 and 3450 feet (1037-1052 m). All three logs

exhibit saturation at approximately 2000 ohm-meters resistivity. Resistivity logs used in mineralized igneous or metamorphic rocks should have a dynamic range of .1 to 100,000 ohm-meters if the true resistivity of the rock is to be measured. Schlumberger (1972) indicates that the DIL/LL8 is inaccurate where formation resistivity is above 100 ohm-meters. In general, the resistivity logs indicate a variable resistivity, 10 to 100 ohm-m from the surface to 2200 feet (661 m), and 100 to greater than 1000 ohm-m from 2200 feet (671 m) to total depth.

Spontaneous Potential Log (SP): The SP was measured during runs one and two of the Dual Induction - Laterolog device. The factor of approximately 2.5 change in R_m , Table 1, between the two runs has had no obvious effect on the SP log, although one would be expected. Many of the perturbations in the SP log, such as seen at 1490 and 1540 feet (455-470 m), correlate with fractures. Deflections are toward the shale line (Schlumberger, 1972), which may reflect the presence of clay gouge in the fractures. These gouge-filled fractures would probably have very low permeabilities.

Natural Gamma Log: This log should reflect varying amounts of uranium, thorium, and potassium in the rocks. Uranium and thorium, if present, would be expected to generate a higher natural gamma response in clays (located in fractures) and in the more acidic rock types. The potassium contribution to the natural gamma log directly reflects the varying amounts of clay, orthoclase, biotite, and sericite in the rock. Other minerals contain potassium but are not significant in the rocks penetrated by the well. A spectral gamma ray tool would quantitatively measure uranium, thorium and potassium, and

would be an effective tool for lithologic identification. Concentrations of uranium and/or thorium in clay gouge and breccia might also delineate fault zones or fractures.

Pumiceous and perlite alluvium in 52-21 has about twice the natural gamma radiation as the alluvium containing only a trace of these constituents. The pumice and perlite, being of rhyolitic composition and therefore relatively potassium-rich, significantly increases the natural gamma radiation of the alluvium. If this correlation is correct, the natural gamma log indicates a sharp bedding boundary at 260 feet (79 m), about 15 feet (4.6 m) deeper than suggested by chip samples. Both the natural gamma log and chip samples place the alluvium-bedrock contact at 570 feet (174 m).

DISCUSSION OF WELL LOG DATA FOR UTAH STATE DRILL HOLE 14-2

Drill Hole Location and Drilling History

Utah State Drill Hole 14-2 is located 2310 feet (705 m) south and 350 feet (107 m) east of the northeast corner of Sec. 2, T27S, R9W, in Beaver County, Utah. The location is within the Roosevelt Hot Springs KGRA. The hole was drilled by Loffland Brothers Company for Thermal Power Company, beginning 9/11/76 and ending 10/14/76, with on-site mud logging service provided by Alpha Beta Gamma Associates, Inc.

The hole was drilled with mud and water to a depth of 3255 feet (993 m), with mud (approx. 8.7 ppg with LCM) to a depth of 3701 feet (1129 m), with mud and salt water (with LCM) to a depth of 4535 feet (1383 m), and with mud and salt water to total depth, 6100 feet (1861 m). At a depth of 5803 feet (1770 m) mud was displaced by cold water and an Eastman multi-shot directional survey was made. The results yielded a measured depth of 5800 feet (1769 m), true depth of 5774.6 feet (1761 m) and bottom hole co-ordinates, relative to collar, of 395.4 feet (121 m) north and 120.2 feet (36.7 m) west. Subsequent to the survey the well began to flow. At total depth a flow test was attempted but the volume exceeded the capacity of a 4 inch (10 cm) flow line. The hole had previously been cased to 1805 feet (551 m) depth. The drillers' log noted that the well had "kicked" while drilling at 1625 feet (496 m).

Geologic Log

Thermal Power Corporation's Utah State 14-2, with a total depth of 6100 feet (1861 m), was completed dominantly in hornblende-biotite-quartz-monzonite, a major phase (Tqm) of the Mineral Mountains pluton (Nielson and

others, 1978; Ballantyne and Parry, 1978). Dark-colored, fine-grained holocrystalline rocks occurring at scattered intervals in 14-2 and ranging in composition from dacite through quartz latite have been previously interpreted as dikes intruding the quartz monzonite. Comparison of these rocks with surface lithologies suggests most are probably xenoliths of the banded gneiss (PGbg) and possibly biotite gneiss (PGn; Nielson and others, 1978, p.14). The quartz monzonite is intruded by biotite aplite porphyry and biotite microgranite, both of which can be assigned to the Tertiary fine-grained granite (Tgr) of Nielson and others (1978). Between roughly 2100 feet and 4050 feet (641-1235 m), the quartz monzonite is also intruded by numerous microdiorite dikes. These dikes are similar to the microdiorite dikes encountered in Utah State 52-21 and 72-16 and are likewise typically strongly altered and mineralized.

Hydrothermal alteration in Utah State 14-2 is similar to that observed in Utah State 52-21 and 72-16. Sericite, chlorite and calcite are the dominant alteration products. The alteration is of weak to moderate intensity above 2050 feet and, except for narrow restricted intervals, very weak below this footage. Disseminated pyrite (or its oxidized equivalent) accompanies the alteration throughout the hole but is particularly abundant in altered microdiorite.

Well Logs

Well logs obtained in Utah State 14-2 and submitted to the Earth Science Laboratory are listed in Table 2 and most are plotted in Plate II. All depths in 14-2 refer to Kelly Bushing at 21.5 feet (6.6 m) above ground level. A discussion of each log follows.

Table 2: Well Logs Obtained in Utah State Drill Hole 14-2;
Roosevelt Hot Springs, KGRA

<u>Log Type</u>	<u>Date</u>	<u>Logging Co.</u>	<u>Digi- tized</u>	<u>Casing Depth</u>	<u>Logged Footage (Ft.)</u>	<u>Fluid Type</u>	<u>Comments</u>
Temperature	9/19/76	Schlumberger	Yes	645	10-1810	FGM	20 hrs. after circulation
Temperature	10/15/76	Schlumberger	Yes	1805	1500-6121	Water	14 hrs. after circulation
Temperature	10/16/76	Agnew & Sweet	Yes	1805	0-6106	Water	6 hrs. after circulation
Temperature	11/15/76	Agnew & Sweet	Yes	1805	40-6091	Water	"Static
Temperature	11/18/76	Agnew & Sweet	No	1805	0-6084	Water	Two consecutive logs do not agree.
Compensated	9/19/76	Schlumberger	Yes	645	600-1794	FGM	
Neutron-Formation	10/15/76		Yes	1805	1812-6121	Water	Limestone grain density 2.71
Density, GR							Fluid density 1.0
Induction -	9/19/76	Schlumberger	Yes	645	650-1809	FGM	$R_m=2.18$ at 81°F , $R_{mf}=2.20$ at 81°F
Electrical Log	10/15/76	Schlumberger	Yes	1845	1812-6118	Water	$R_m=R_{mf}=1.20$ at 70°F
Borehole Comp.							
Sonic Log	9/19/76	Schlumberger	Yes	645	600-1799	FGM	
Gamma Ray	10/15/76	Schlumberger	Yes	1805	1812-6112	Water	
SP	9/19/76	Schlumberger	Yes	645	650-1809	FGM	Logged simultaneously with
SP	10/15/76	Schlumberger	Yes	1805	1812-6118	Water	Induction-electric-log.

Temperature Logs: Four temperature logs and the date and time after circulation or flow when each log was obtained are shown in Plate II. Without more information about these events and their timing, it is difficult to learn much from the temperature logs. However, a few observations can be made.

The Schlumberger log of 9/19/76 was obtained 20 hours after circulation when the hole was at a depth of 1805 feet (551 m). The many perturbations in the log below 900 feet (275 m) such as seen at 940, 1200, and 1620 feet (287, 366 and 494 m) indicate zones of permeability. A fairly good correlation exists between these permeable zones, the amount of limonite observed in the chip samples, and either cracks or fractures noted on other logs.

A similar characteristic is observed in the Schlumberger log of 10/15/76 which was obtained 14 hours after circulation. The slower recovery of intervals 2000 to 2900 feet (610-885 m), 4200 to 4900 feet (1281-1495 m), and 5300 to 5600 feet (1617-1708 m) also suggest these intervals are permeable. The rock type and geophysical logs suggest the permeability is fracture related.

The very small temperature gradient below 1500 feet (458 m) strongly suggests that 14-2 resides in a convective geothermal system. Quite possibly the hole parallels and/or intersects one or more fractures throughout its length. Above 1500 feet (485 m) the temperature log suggests predominately conductive heat flow. The Agnew and Sweet log of 11-15-76 indicates equilibrium reservoir temperatures of approximately 490°F (254°C) at depth.

A rather sharp shift in the temperature profile, about 32°F (18°C) on the

11/15/76 log, occurs between 2810 and 2860 feet (857-872 m) just above a fracture interval at 2860 to 2910 feet (872-888 m) which, in turn, corresponds to an interval of higher total sulfides. This temperature shift has migrated up-hole with time after circulation. The shift observed in the 10/15/76 log occurs below the fractured interval. This feature in the temperature log may indicate the boundary between two distinct convective systems. This break corresponds to a change from hematite (oxydizing zone) to sulfide (reducing zone) mineralization in the rock.

Caliper Log: The caliper log is obviously not accurately depicting borehole diameter (bit size/hole size shown for reference) but does reflect borehole variations. Borehole enlargements like the one at 2900 feet (885 m), and those between 3620 and 3650 feet (1104-1113 m) and between 4200 and 4240 feet (1281-1293 m) are characteristic of washouts or caving on fractures.

Interval Transit Time (velocity) Log: The interval transit time is simply the reciprocal of the acoustic velocity of the formation. The measurement is the time difference between first arrivals at two receivers some fixed distance apart, typically a separation between 2 and 6 feet (.6-1.8 m). The log is most often used to determine porosity using the empirical, time average equation $\phi = (\Delta t - \Delta t_m) / (\Delta t_f - \Delta t_m)$ where Δt is the measured travel time, Δt_m is the matrix travel time and Δt_f is the fluid travel time. Fracture porosity may affect the log in a similar way. In hard rocks the velocity log can be used to estimated the RQD (Rock Quality Designation is the measure of the length of pieces of core over four inches over the total length of the core run) of the rock (Glenn and Nelson, 1977) or fracture porosity (Stierman and Kovach, 1979).

As noted on the log, sharp spikes in the signature are due to cycle skipping. Other large excursions in the log, an example can be seen at 2900 feet (885 m) are a result of increased travel times in fractured rock. In these situations, the source of the response can be attributed to borehole enlargement, although the borehole compensated log, which this log is, should minimize this effect.

Neutron Porosity Log: The neutron porosity log is calibrated in limestone units. Matrix mineralogy different from limestone will give a different, apparent porosity rather than the true porosity. One significant matrix effect in crystalline rocks is the apparent porosity produced by the water in hydrous minerals (Nelson and Glenn, 1975). Borehole enlargements often create large apparent porosities such as seen between 4200 and 4240 feet (1281-1293 m).

Density Porosity/Bulk Density Log: The density porosity log is simply the porosity computed from the bulk density log where some grain density, ρ_g (a limestone grain density of 2.71 gm/cm³ in this case), is assumed. The porosity is then

$$\phi = (\rho_g - \rho_b) / (\rho_g - 1)$$

where ρ_b is the bulk density and the fluid density is assumed to be 1 gm/cm³.

If the grain density varies appreciably, which it can in altered and mineralized crystalline rocks, the porosity will not be very accurate. The density porosity is obviously too high and shows far more variability than the neutron porosity log. The log is certainly suspect. The bulk density appears

to range between 2.50 and 2.75 gm/cc. If the true average grain density for these rocks is between 2.60 and 2.75 gm/cc, the porosity would lie between zero and 6 per cent. This range certainly compares more favorably with the neutron porosity.

Resistivity Log: A short normal log was obtained between 650 and 1810 feet (198-552 m) and a 6FF40 (Schlumberger tool) induction log was obtained between 650 and 6100 feet (198-1861 m). Log runs were made on two separate occasions (Table 3) 650 to 1810 feet (198-552 m) and 1800 to 6100 feet (549-1861 m). The mud resistivity was lower for the second log. The conductivity is very low as would be expected in these rock types. As noted earlier, a resistivity log having several decades of dynamic range would be more appropriate in these rock types.

The highly fractured rock above 2050 feet (625 m) has a higher conductivity than rock in the rest of the drill hole, which may reflect a higher porosity in the more fractured rock. Below 2050 feet (625 m) small perturbations in the conductivity log occur opposite fractures, otherwise the log is featureless and may be saturated most of the time.

Spontaneous Potential Log: The spontaneous potential (SP) was measured with the resistivity tool. The break in the log at 1810 feet (552 m) occurs where the logs obtained on two separate occasions meet. The log above 1810 feet (552 m) shows very little character whereas the log below 1810 feet exhibits large fluctuations in the SP. The mud resistivity change is close to a factor of two between the two measurements, but this change is not large enough in itself to explain the change in the SP log. However, a contrast in

resistivity between the formation water and borehole fluid must exist to generate meaningful SP deflections, which may not have been the case during the first SP measurement.

In a sand-shale sequence where the formation water is more saline than the mud filtrate, the SP log will deflect to the left opposite the more permeable sand formations. If the formation water is less saline, the deflection for the permeable bed will be to the right (Schlumberger, 1972).

Lenzer et al. (1976) report that the total dissolved solids (TDS) in two wells about one-half mile east of well 14-2 are 6442 and 7067 ppm. The average TDS is about 6754 ppm which is almost identical to the 6752 ppm reported by Ward et al. (1978) for well 72-16. Using this average TDS value and a reservoir temperature between 400°F and 500°F (204-260°C), we estimate the formation fluid resistivity to be approximately .17 ohm-meters (Chart on p. 54 of Gearhart-Owen Industries Reference Data Handbook). The Schlumberger log heading notes that the borehole fluid resistivity is 1.2 ohm-m at 70°F (21°C), which implies a mud resistivity of about .22 ohm-meters at reservoir temperatures. Therefore, very little contrast actually exists between the resistivities of the two fluids. The SP logs show conventional left deflection between 2050 and 2850 feet (625-869 m) (boundaries not well defined), between 3250 and 3850 feet (991-1174 m), and between 5410 and 5750 feet (1650-1754 m). The upper and lower two intervals correspond with permeable zones interpreted from the temperature logs.

Natural Gamma Log: Three natural gamma logs are shown in Plate II. Two logs are shown in the interval above 1810 feet (552 m) and one log is shown

below 1810 feet (552 m). The two logs above 1810 feet are included to demonstrate repeatability.

A distinct, high natural gamma radiation occurs between 1550 and 2070 feet (473-631 m) and correlates almost entirely with the biotite microgranite. This same interval contains an estimated 5% or more hematite. The "limonite" above 1550 feet (473 m) is goethite. Most, but not all, natural gamma spikes below 2070 feet (631 m) correlate with observed biotite microgranite. The microgranite intervals between 200 and 500 feet (61-153 m) also correlate with locally higher natural gamma radiation. The mineral allanite may contain as much as 2.23 weight per cent ThO_2 and 30 to 650 ppm uranium (Deer et al., 1975, p.68). This mineral is present in both the biotite microgranite and the hornblende-biotite quartz monzonite. Another trace element, zircon, is present in these two rock units and it can contain uranium.

Some aspects of the natural gamma log may reflect concentrations of uranium and thorium or their daughter products as a result of the movement of the geothermal fluids (Wollenburg, 1976). A spectral gamma log in well 14-2 might prove very useful. Currently we are analyzing chip samples for uranium and thorium content.

DISCUSSION OF WELL LOG DATA FOR UTAH STATE DRILL HOLE 72-16

Drill Hole Location and Drilling History

Utah State Geothermal well 72-16, located 990 feet (302 m) south and 990 feet (302 m) west of the northeast corner of Sec. 16, T27S, R9W, Beaver County, Utah, was drilled by Loffland Brothers Company for Thermal Power

Company. Drilling began on 10/22/76 and was completed on 12/31/76. The hole was air-drilled to 85 feet (26 m) and was drilled with mud thereafter. All depths quoted for 72-16 and shown in Plate III refer to Kelly Bushing (KB) which was 21.7 feet (6.6 m) above ground level.

Alpha Beta Gamma Associates Incorporated (ABGA) provided on-site logging services: drilling rate, lithology, temperature, mud gas, H₂S and CO₂. Only the drilling rate is included in this report (Plate III). A detailed well summary report has been submitted by Thermal Power Company (1977). A summary of drill bit size and casing diameters are given in Plate III.

The drillers' log indicates that the well flowed water at three points during drilling: 312 feet, 514 feet, and 633 feet (95, 157 and 193 m). Complete loss of circulation occurred at a depth of 1245 feet (382 m). These observations are qualitative and do not preclude other flow events which were neither recorded nor reported. Mud weight was used to control flow during drilling. Cemented casing to 1098 feet (335 m) eventually completely sealed the flow zones at 312, 514, and 633 feet (95, 157 and 193 m). Total open-hole completion is apparently 156 feet (48 m), between depths of 1098 and 1254 feet (335-382 m). Our records are not clear, but the hole may have been cemented between 1098 and 1144 feet (335-345 m), which would leave about 101 feet (31 m) rather than 156 feet (48 m) of open hole.

Geologic Log

Utah State 72-16 penetrated 475 feet (145 m) of arkosic alluvium and 779 feet (238 m) of dark poorly- to well-foliated gneisses tentatively correlated with the Precambrian banded gneiss (P6bg) and hornblende gneiss (P6gn)

(Nielson and others, 1978). Coarse-grained granitic chips associated with the gneisses probably represent both felsic metamorphic segregations and granitic dikes of Tertiary age. A strongly altered biotite-hornblende microdiorite dike, similar to those encountered in 52-21, intrudes the banded gneiss between 600 and 620 feet (183-189 m).

Bedrock alteration is dominated by erratic, weak to moderate chloritization of mafic minerals and clay-sericitization of plagioclase, locally accompanied by minor disseminated pyrite (Nielson and others, 1978; Rohrs and Parry, 1978).

Two horizons in the alluvium of 72-16, 295 feet to 320 feet (90-98 m), and 430 feet to 475 feet (131-145 m) are strongly silicified and weakly pyritized. These horizons may represent siliceous caprocks, fossil opal aprons developed at former ground levels, or alteration along post-alluvial faults. Hot water entries have been noted at 312 and 514 feet (95 and 157 m) which either lie within or below these silicified zones.

Well Logs

Well logs obtained in Utah State 72-16 and submitted to the Earth Science Laboratory are listed in Table 3 and most are plotted in Plate III. A discussion of each log follows.

Drilling Rate: The rate of bit penetration, in minutes/foot, during drilling is given in Plate III. This rate will depend on a number of things, (Cunningham, 1978) among them: weight on the bit, mud weight, type of bit, circulation, bit wear and rock type. Sometimes drilling rate increases in

Table 3: Well Logs Obtained in Utah State Drill Hole 72-16;
Roosevelt Hot Springs, KGRA

<u>Log Type</u>	<u>Date</u>	<u>Logging Co.</u>	<u>Digi- tized</u>	<u>Casing Depth</u>	<u>Logged Footage (Ft.)</u>	<u>Fluid Type</u>	<u>Comments</u>
Drilling Rate	10/22- 11/19/76	Alpha Beta Gamma Assoc.	Yes	---	86-1245	Mud	Logged during drilling
Temperature	11/05/76	Schlumberger	Yes	580	0-525	Air	
Temperature	11/17/76	Agnew & Sweet	Yes	580	0-1210	NA	"Static", Logged in 5" drill pipe
Temperature	12/21/76	Schlumberger	Yes	1098	50-1012	Water	
Temperature	3/30/77	Agnew & Sweet	Yes	1098	0-1229	NA	"Static"
Cement Bond Log	11/04/76	Schlumberger	No	580	0-522	Water	
Cement Bond Log	12/20/76	Schlumberger	No	1098	20-999	Water	
Gamma Ray	11/04/76	Schlumberger	Yes	580	0-522	Water	Run in casing with VDL
Pressure	3/30/77	Agnew & Sweet	No	1098	0-1229	Water	
Pressure Build Up	4/5&6/77	Agnew & Sweet	No	1098	hung at 1226	Water	

fractured rock. The fractured rock, in turn, is often associated with fluid flow or lost circulation zones. This correlation occurs at 312, 514, and 1245 feet (95, 157, and 380 m) in 72-16 but significantly, not at 633 feet (193 m).

Temperature Logs: Four temperature logs obtained in 72-16 have been submitted to ESL; these logs are noted in Table 3 and are plotted in Plate III. Notes from the drillers' log, included in Plate III, are very qualitative and can not be assumed to be complete or scientifically accurate. However the information is important to evaluation of temperature logs.

Removal of the drill rig and well shut-in on 12/31/76 is the last event noted in our records before the Agnew and Sweet temperature log was obtained on 3/30/77. A maximum of three months of shut-in may have occurred and the 3/30/77 temperature log should closely depict the true reservoir temperatures and geothermal gradient in the vicinity of 72-16. A maximum temperature of 468.8°F (243°C) was observed at maximum survey depth of 1229 feet (375 m).

Both the Agnew and Sweet temperature logs and the Schlumberger temperature logs of 11/5/76, 11/17/76 and 12/21/76 were obtained shortly after some activity in the borehole, such as setting casing, a short flow test and circulation. Without knowing exactly what activities preceeded the logs, no quantitative and very little qualitative interpretation of these logs is possible. The date each casing string was set and cemented is also shown in Plate III. This information indicates that most of the temperature data were obtained in casing. Although the logs show characteristics similar to temperature injection/recovery profiles, one should be careful in extracting any information from these logs.

Formation water was first noted while drilling 72-16 at 312 feet (95 m) depth, which is at the base or just below an interval of cemented alluvium. The hole was cemented between 286 feet and 312 feet (87 and 95 m) before it was deepened. The hole was drilled to 585 feet (178 m) and 13 3/8" (34 cm) casing cemented in place prior to obtaining the first temperature log, Schlumberger log 11/5/76. This log indicates a 300°F (149°C) plus thermal high between 312 feet and 585 feet (95 and 178 m). A small amount of water flow into the drill hole also had been noted during drilling at 514 feet (157 m) (ABGA). These two water entries are clearly hot water entries and the entry at 312 is probably at or near the top of the system. Fault breccia makes up a good portion of the chips between 470 feet and 500 feet; therefore the flow at 514 feet (157 m) may be related to a fault. Unfortunately no chips were recovered in this flow zone.

The Agnew and Sweet temperature log of 11/17/76 was obtained within 48 hours of drilling to 1245 feet (380 m) and with casing to 580 feet (177 m). Our records also indicate that the log was obtained inside 5 inch (13 cm) drill pipe to total depth. The character of the log suggests that the drill hole was circulated sometime prior to logging. The log indicates the flow zone at 633 feet (193 m) recovers more rapidly than the one at the bottom of the hole. This result would be more meaningful if information about the flow prior to logging were available.

Temperature gradients were computed from the Agnew and Sweet log of 3/30/77 and are shown in Figure 5. Three gradient curves are shown, each corresponding to a different data interval average. All three gradient curves

Figure 5

show the same behavior. The gradient is very high above about 350 feet (107 m) depth and appears to asymptote to 100°C/km below 900 feet (275 m) depth.

We believe temperature log 4 or the gradient computed from this log, the lithology, and the drillers' notes indicate that the present top of the geothermal system in the vicinity of 72-16 lies between 290 and 320 feet (88-98 m) depth. The cemented alluvium between 430 feet (131 m) and the top of the bedrock at 460 feet (140 m) is probably related to fluids flowing from the fault at 480 feet (146 m) in the bedrock. This fault is permeable and permits fluid to move from the bedrock into the lower portion of the alluvium. The lower gradient in the interval corresponding to the base of the alluvium and the top of the bedrock suggests that the heat flow in this zone includes convection. A more thorough discussion of heat flow is given in a later section of this report.

Cement Bond Log: Two cement bond logs (CBL) were obtained during the drilling of 72-16, one on 11/5/76 after setting the 13 3/8" (34 cm) casing and the other on 12/21/76 after setting the 9 5/8" (24 cm) casing. The well summary report submitted by Thermal Power Company claims the CBL on 11/5/76 shows "excellent bond from surface to 100 feet (31 m), fair bond from 100 to 260 feet (31-79 m) and excellent bond from 260 to 522 feet (79-159 m, top of cement plug inside 13 3/8 inch, 34 cm, casing)" and the CBL on 12/21/76 shows "excellent bonding from 999 feet (305 m) up to 85 feet (26 m), then good to fair bonding from 85 feet (26 m) to the surface." Copies of the cement bond logs are not included here but are available from Rocky Mountain Well Log Services, Denver, Colorado. We believe the CBL shows poor to fair bonding

below 435 feet (133 m). If this is the case, fluid may be moving down behind casing and entering the borehole at the base of the casing.

Natural Gamma Log: A natural gamma log was run simultaneously with the CBL on 11/5/76. Hence, the log was obtained in casing. The log shows an apparent linear increase in radioactivity with depth. This increase could be due to an increase in temperature with depth affecting the instrument, an increase in gamma emitters with depth, or an effect of hole completion. This log was obtained the same day as temperature log 1 in Plate III. No uniform correlation with depth is evident between these two logs. Therefore, we believe the increase in natural gamma radiation with depth can be attributed to changes in mineralization or hole completion. However, note that the natural gamma log is higher over the high-temperature interval between 300 and 525 feet (92-160 m).

Two short intervals of highest natural gamma radiation are evident between 285 and 325 feet (87-99 m) and between 490 feet (150 m) and the end of the log at 522 feet (159 m). The upper interval correlates with a silica-cemented interval in the alluvium. This interval also contains a notable amount of sulfides. Since the alluvium is all of fairly uniform mineralogy, the higher natural gamma radiation is believed to reflect mineralogy associated with the cementation and/or with the sulfides noted in this interval. Uranium occurrences, for example, are often associated with an increase in sulfide mineralization. The lower interval of higher natural gamma radiation could be thicker since it occurs at the end of the log. This interval is just below a second interval of cemented alluvium and occurs where substantial fault breccia was observed in the chips.

DISCUSSION OF WELL LOG DATA FOR THERMAL GRADIENT DRILL HOLE GPC-15

Drill Hole Location and Drilling History

Geothermal gradient drill Hole GPC-15, located in Sec. 18, T27S, R9W, Beaver County, Utah, was drilled as a geothermal observation well for Geothermal Power Corporation. It was drilled by Darrah Drilling Corporation. Well-site logging services were provided by Helton Engineering and Geological Services, Inc. The day drilling began is unknown but it was a few days before 7/16/78. The hole was completed on 7/28/78. The hole was drilled completely in alluvium to a depth of 1900 feet (580 m). Wireline logs were run 7/25/78 through 7/27/78 and then 1890 feet (577 m) of 1 1/2 inch (3.8 cm) casing was cemented in the hole.

Geologic Log

GPC-15 was completed entirely in unaltered arkosic alluvium, compositionally similar to the alluvium penetrated in the other three drill holes (Plate IV). Average grain size in the alluvium decreases downhole, reflecting a progressively higher energy depositional environment with decreasing age. This environment, in turn, was probably dependent on increasing relative uplift of the Mineral Mountains fault block east of GPC-15.

Traces of probable fault gouge erratically distributed below 790 feet (241 m) in GPC-15 may be derived from post-alluvial fault zones. Several lost-circulation intervals below this depth may correspond to these zones.

The lithologic log was determined from a study of chip samples by M.J. Bullett and the second author, J. B. Hulen. Since the alluvium shows very little mineralogic variation, we felt it might prove useful to graphically represent the grain size variation in the lithologic log. Between the surface and 800 feet (244 m) depth, the grain size appears to decrease uniformly with depth. Below 800 feet (244 m), the alluvium is an interbedded sequence of poorly- to well-sorted, fine- to medium-grained beds.

The grain size variation correlates poorly with the well logs. Local bulk density increases between 1700 and 1800 feet (519-549 m) correlate with well-sorted silt horizons.

Well Logs

Well logs for GPC-15 submitted to ESL by Geothermal Power Corporation are listed in Table 4. The logs were digitized and are shown plotted in Plate IV. The lithologic log is also included in Plate IV. The hole was drilled with a 6 1/2 inch (16.5 cm) bit and was cased with 1-1/2 inch (3.8 cm) steel casing. The temperature data were recorded inside casing but all other logs were recorded in the open hole. A brief description of each log follows.

Temperature Logs: Two temperature surveys were made, exactly one month apart. The first survey was obtained about three days after the hole was completed. The ambient day-time temperature during this time was averaging over 100°F (38°C), which may explain the increasing temperature near-surface on both logs. Although the temperature log is plotted as a continuous measurement, the data were actually collected at discrete points, every 20 feet (6 m) for the 7/30/78 log and every 10 feet (3 m) for the 8/30 - 31/78 log.

Table 4: Well Logs Obtained in Thermal Gradient Drill Hole GPC-15;
Roosevelt Hot Springs, KGRA

<u>Log Type</u>	<u>Date</u>	<u>Logging Co.</u>	<u>Digi- tized</u>	<u>Casing Depth</u>	<u>Logged Footage (Ft.)</u>	<u>Fluid Type</u>	<u>Comments</u>
Temperature	7/30/78	N/A	Yes	1890'	20-1889	N/A	Discrete meas. every 20'
Temperature	8/30/79	N/A	Yes	1890'	10-1880	N/A	Discrete meas. every 10'
Borehole Comp. Sonic	7/25/78	Schlumberger	Yes	18'	50-1889	FGM	Digitized. 560'-1889'
Comp. Formation Density/Caliper	7/26/78	Schlumberger	Yes	18'	50-1889	FGM	
Gamma Ray Induction	7/25/78	Schlumberger	Yes	18'	40-1885	Mud	$R_m=4.11$ @ 78°F, $R_{mf}=3.67$ @ 78°F $R_m=2.23$ @ BHT 144°F.
Electric Log LL8/6FF40/SP							

All depths relative to KB (+5 feet).

Figure 6 shows the temperature gradient in GPC-15 as computed from the Pruett wireline temperature measurements of 8/30 - 31/78. The data were averaged on 100 foot (31 m) intervals using linear regression. We will show later in a study of other logs that the water table is approximately located at 545 feet (166 m) depth. The gradient appears to be approximately 150°C/km above the water table and about 100°C/km for some depth below the water table. Below 1200 feet (366 m) depth the gradient sharply decreases to a minimum of 11°C/km at 1360 feet (415 m) depth. The gradient then smoothly increases to the bottom of the hole. The change in gradient at the water table may reflect both a change in thermal conductivity between the saturated and unsaturated alluvium and a change from purely conductive heat flow above the water table to convective and conductive heat flow below the water table. The interval of lower temperature gradient centered at 1360 feet (415 m) depth may reflect inflow of cooler water at that depth.

Caliper Log: The caliper log shows the hole, in many intervals, to be about .5 inches (1.3 cm) smaller than the bit size used to drill the hole. The caliper is certainly improperly calibrated. The engineering report indicates that a 6-1/2 inch (16.5 cm) bit was used to drill the hole while a 6-1/4 inch (15.9 cm) bit size was recorded on the log heading. The irregularity of the borehole wall is expected since the drill hole is located in poorly consolidated alluvium.

Interval Transit Time (velocity) Log: As expected, the travel time decreases (velocity increases) with depth. The biggest decrease occurs between 1300 and 1350 feet (397-412 m). The log is probably reflecting the

Figure 6

degree of cementation and compaction in the alluvium. The interval transit time log was too poor of quality above 550 feet (168 m) to digitize.

Bulk Density Log: The bulk density log is from a Schlumberger Compensated Formation Density Log. The log shows a small increase in bulk density with depth and one sharp increase at 545 feet (166 m). The bulk density increases from 2.0 to 2.1 gm/cc between 50 and 545 feet (15-166 m). At 545 feet (166 m) the bulk density shifts to 2.3 gm/cc. From 545 feet (166 m) to total depth the bulk density increases from 2.3 to 2.45 gm/cc. These bulk densities are averages and their increases with depth probably reflect compaction in the alluvium. The density change at 545 feet (166 m) probably occurs at the water table. This depth is consistent with published data (Mower and Cordova, 1974).

The following equation relates bulk density to grain density and porosity:

$$\rho_b = \rho_g(1-\phi) + \rho_f\phi$$

where ρ_b , ρ_g and ρ_f are the bulk, grain and fluid densities and ϕ is porosity. Above the water table (545 feet, 166 m, depth) ρ_f is near zero, ρ_b is 2.05 gm/cc (average) and we will assume ρ_g is 2.65 gm/cc. These values yield a porosity of 23 per cent. Below the water table ρ_b is 2.28 gm/cc (average) and ρ_f is 1.0 gm/cc (water). These values yield a porosity of 22 per cent. These two results are quite close and would support the interpretation of the bulk density change and water table coincidence at 545 feet depth. Also, the drop in velocity log quality above this depth can be attributed to less signal amplitude, which could reflect the change from saturated to unsaturated

alluvium. We shall see that the resistivity logs will support this interpretation.

Resistivity Log: This log is a Schlumberger 6FF40 Induction log and Laterolog 8. The log quality in the upper part of the hole was too poor to reproduce. The sharp increase in resistivity at 540 feet (165 m) is attributed to a change from saturated to unsaturated alluvium. The hole was filled with drilling mud for logging purposes and this explains the presence of a log response above the water table.

The conductivity varies between 25 and 220 mhos/m or 40 and 4.55 ohm-meters. The resistivity values above the water table do not represent intrinsic conditions. The decreasing conductivity below 1450 feet (442 m) probably reflects a decreasing porosity which also can be noted in the density and velocity logs.

Spontaneous Potential Log: The SP log exhibits some variability which probably reflects the variability of clay in the alluvium. The SP log also shows an increase to the right (shale line direction) with depth. The decrease in porosity with compaction interpreted previously from the other logs could be accompanied by a decrease in permeability. Also, an increasing amount of fine grains with depth could decrease the porosity. The decrease in permeability would shift the SP log to the right.

Natural Gamma Log: The natural gamma log shows a higher degree of variability between 160 and 525 feet (49-160 m) depths than it does elsewhere in the drill hole. No obvious lithologic correlation with this characteristic of the log is evident.

ESTIMATE OF ROCK PROPERTIES FROM WELL LOGS

We will estimate some of the bulk physical properties of the geologic rock types penetrated by the four holes discussed earlier. The well logs give some of the quantities directly: sonic compressional wave velocity, bulk density, electrical resistivity, and porosity. Other logs give indirect measurement of some quantities: porosity, relative fluid permeability, fracture intensity, and rock quality. Other rock properties can be measured directly or indirectly via logging tools; for example, magnetic susceptibility, relative amounts of U, Th and K, could be, but were not measured in the holes studied here.

The sonic velocity log can be used to obtain compressional, V_p , and shear wave, V_s , velocities. Only the compressional wave velocity can be determined from the interval transit time log. In combination with the density log, the velocity log (when both V_p and V_s are recorded) can be used to compute Poisson's ratio, bulk and shear moduli and an acoustic velocity reflection coefficient.

An interval transit time log was obtained in three holes: 52-21, 14-2 and GPC-15. The log in drill hole GPC-15 was entirely within alluvium and logs in the other holes were recorded primarily in the bedrock. Unless otherwise noted, numbers cited for various rock properties will be averages of selected data within the indicated borehole depth intervals. Data obviously affected by noise and borehole conditions are eliminated.

Alluvium

Except for natural gamma logs in 72-16 and 14-2 and resistivity logs in 52-21, the only significant logs in alluvium were obtained in GPC-15. The alluvium penetrated by all four holes is arkosic and exhibits only minor differences in sorting and mineralogy. Only in 72-16 have we interpreted any fault intercepts in the alluvium. These intercepts are characterized by fault breccia fragments in the chips and higher natural gamma radiation than observed in the surrounding alluvium.

The following discussion is based on logs in GPC-15 and shown in Plate IV. The distinct change in bulk density at 540 feet (165 m) has been interpreted to be the water table. The bulk density to 450 feet (137 m) is locally variable, 1.8 to 2.4 gm/cc, but tends to average about 2.05 gm/cc; between 450 and 540 feet (137-165 m) it is slightly higher, approximately 2.1 gm/cc. Below 540 feet (165 m) the bulk density generally increases with depth, from 2.23 gm/cc at 540 feet (165 m) to 2.46 gm/cc at 1890 feet (577 m). Several intervals below 1585 feet (483 m) have bulk densities averaging about 2.5 gm/cc. The observed increase in magnetite and ilmenite in these intervals would produce higher bulk densities. We estimate up to 5% magnetite/ilmenite in some ten foot sample intervals. Assuming 4.95 gm/cc for the magnetite/ilmenite grain density, 2.65 gm/cc average grain density for the remaining mineral aggregate, and a porosity of 20%, we compute a bulk density of 2.51 gm/cc. If we did not consider the heavy minerals in the computation and simply used a grain density of 2.65 gm/cc, we would calculate a lower porosity of 10% for the alluvium in these intervals. Just below the water table the bulk density is about 2.28 gm/cc. Using 2.65 gm/cc for the grain

density we obtained a porosity of 22%. If significant amounts of heavy minerals are present the porosity could be higher. In general it appears that porosity may be decreasing with depth, from about 22% at the water table to 15% or less at the bottom of the hole.

A crossplot of interval transit time versus bulk density is shown in Figure 7. The data points are 20 foot (6 m) averages. Figure 7(a) shows the data plotted for the entire interval, 558 to 1898 feet (170-579 m), which implies that the alluvium is a uniform unit. The data appear to follow a straight line with a slope of .00444 gm-ft/cc- μ sec and an intercept of 2.79 gm/cc. This result could only be interpreted by using unreasonable values for grain density and matrix travel time and is therefore believed to be incorrect.

Figure 7(b) shows the same data but with but separate, identifiable units of the alluvium distinguished on the plot by different symbols. Four distinct units are identified. Note that each interval follows a parallel trend as identified by interpreted straight lines labeled 2 through 5 in Figure 7(b). This result is interesting since it indicates that the alluvium is better cemented or consolidated with depth and that porosity is decreasing slightly with depth. As noted earlier, the increase in fine grains with depth could reduce the porosity as well. Also, the slope of the $\Delta t - \rho_b$ relationship, $(\rho_g - 1)/B$, remains constant with depth. With the data interpreted as in Figure 7(b), both bulk density and interval transit time yield consistent values for porosity and grain density.

Drill Hole GPC 15
 INTERVAL TRANSIT TIME - BULK DENSITY CROSSPLOTS
 (See text for explanation)

Figure 7

The bulk density, ρ_b is defined in terms of grain density, ρ_g , fluid density, ρ_f , and porosity, ϕ :

$$\rho_b = \rho_g(1-\phi) + \rho_f\phi.$$

This equation can be modified to distinguish the grain density, ρ_g as a density average of most common rock-forming minerals present and ρ_m , the average density of heavy minerals such as magnetite, ilmenite, and pyrite.

The above relation for ρ_b becomes

$$\rho_b = \rho_g(1-\phi-x) + \rho_f\phi + \rho_mx$$

where x is the volume fraction of the heavy minerals. The travel time relation is (Wyllie et al., 1956, 1958):

$$\phi = (\Delta t - \Delta t_m) / (\Delta t_f - \Delta t_m)$$

where the terms have been previously defined. Alternatively, Pickett (1973) writes

$$\Delta t = \Delta t_m + B\phi$$

where B is a constant. The crossplot equation is simply

$$\rho_b = \rho_g(1-x) + \rho_mx + \left(\frac{\rho_g - \rho_f}{B}\right)\Delta t_m - \left(\frac{\rho_g - \rho_f}{B}\right)\Delta t$$

or

$$\rho_b = a - b\Delta t$$

where

$$a = \rho_g(1-x) + \rho_mx + \frac{\rho_g - \rho_f}{B} \quad (\text{Intercept})$$

and

$$b = \frac{\rho_g - \rho_f}{B} \quad (\text{Slope}).$$

The values of a and b for each straight line in Figure 7 have been determined and define the following relationships:

1. $\rho_b = 2.79 - .00444\Delta t$
2. $\rho_b = 3.37 - .0091\Delta t$
3. $\rho_b = 3.31 - .0091\Delta t$
4. $\rho_b = 3.22 - .0091\Delta t$
5. $\rho_b = 3.18 - .0091\Delta t$

where the equation numbers correspond to the line numbers in Figure 7.

Table 5 summarizes the estimates of Δt_m and B for three grain densities 2.60, 2.65 and 2.70 gm/cc and average values of ρ_b and Δt read from Figure 7 for each distinct interval. The three grain densities are included to indicate the sensitivity of the analysis to grain density variations. In the absence of any appreciable amounts of heavy minerals, the grain density is probably very close to 2.65 gm/cc. In the lower interval 1588 to 1898 feet (484-579 m), where up to 5% magnetite/ilmenite has been noted in 10 foot (3 m) chip samples, the grain density might be closer to 2.70 gm/cc. The results suggest that the porosity is about 23% just below the water table and decreases with depth to 14% to 19% at the bottom of the hole. The acoustic velocity varies from about 8200 ft/sec (2.5 km/sec) just below the water table to 14,000 ft/sec (4.3 km/sec) at the bottom of the hole.

Note that the change in interval transit time and bulk density is greatest between the intervals above and below 1318 feet (402 m). The interpretation is that both a porosity decrease and a cementation increase

Table 5: Summary of bulk density-interval transit
time crossplot interpretations, GPC-15

Hole Interval Feet (meters)	ρ_b gm/cc	Δt $\mu\text{sec}/\text{ft}$	ρ_g gm/cc	Δt_m $\mu\text{sec}/\text{ft}$	a gm/cc	B ft/ μsec	ϕ %
558-658 (170-201)	2.28	122	2.60	84.6	3.37	176	20
			2.65	79.1		181	23
			2.70	73.6		187	26
658-1318 (201-402)	2.29	112	2.60	78.0	3.31	176	19
			2.65	72.5		181	22
			2.70	67.0		187	24
1318-1518 (402-463)	2.35	95	2.60	68.1	3.22	176	15
			2.65	62.6		181	18
			2.70	57.1		187	21
1518-1898 (463-579)	2.39- 2.46	77-88	2.60	63.5	3.18	176	8-14
			2.65	58.2		181	10-16
			2.70	52.8		187	14-19

occur below 1318 feet. This change also correlates with a distinct change in geothermal gradient, Figure 6. The gradient change is probably only in part due to these changes in rock properties. Cooler water infiltration or convection could create the observed temperature gradient changes.

The resistivity log in Utah State 52-21, Schlumberger's Dual Induction Laterolog 8 tool, indicates no mud invasion into the formation and a variable resistivity profile with depth as follows:

<u>Depth of Interval</u> feet (meters)	<u>Resistivity</u> ohm-m
183-245 (56-75)	100-200
245-390 (75-119)	10-40
390-560 (119-171)	10-15

Also the upper 80 feet (24 meters) bedrock shows an increase in resistivity with depth, suggesting a weathered, fractured surface layer of this thickness in the bedrock.

Archie's law, which is $R_t/R_w = \phi^m$, with m equal to 2 and using a porosity of 20%, yields formation water resistivities, R_w , in the range 0.52 to 2.1 ohm-m. Formation resistivities, R_t , for the alluvium below 245 feet (75 m) were used in the calculation. At the formation temperatures indicated, these resistivities reflect a salinity range of 2000 to 7000 ppm.

Igneous and Metamorphic Rocks

Not enough study has been completed to delineate any distinct correlation between physical properties and these rock types. Indeed no such correlation may exist. However, a summary of acoustic velocity, bulk density, neutron porosity and electrical resistivity as a function of depth for drill holes

Utah State 14-2 and 52-21 is given in Table 6. These two drill holes intersect quite different lithologies; 14-2 is in hornblende, biotite, and quartz monzonite throughout most of its length while 52-21 intersects a variety of gneisses and granitic rocks.

The velocity, density, neutron and resistivity logs all exhibit wide variability to a depth of 2200 feet (671 m) in 14-2 and 2680 feet (817 m) in 52-21. The log behavior, in each case, above these depths is indicative of an abundance of open or clay-filled fractures. Below these depths, fractures may be equally abundant but they do not strongly influence the log response.

Seismic velocities can reflect this fracturing in the igneous and metamorphic rocks. Stierman and Kovach (1979) describe results where borehole acoustic log velocities correlated quite well with seismic velocity determinations. Core analysis yielded an average velocity of about 6 km/sec, for an appropriate confining pressure, whereas the well loss indicated an approximate average of 3 km/sec with the highest velocity being 4.34 km/sec. Gertson and Smith (1979) have interpreted velocities in the east-west Negro Mag Fault (i.e., Negro Mag Wash) area of 3.3 to 4.0 km/sec. In both cases the low velocities can be attributed to macroscopic cracks which may be fully saturated and which remain open under increasing confining stress; that is, they remain open with depth. The acoustic logs in 14-2 and 52-21 indicate the decreasing importance of these fractures below 2200 and 2680 feet (671 and 817 meters), respectively, on velocity.

Below these depths, the neutron porosity and bulk density logs respond primarily to lithology. Figure 8 is an abstracted set of logs from 52-21

**TABLE 6: Summary of Acoustic Velocity, Bulk Density, Neutron Porosity
and Electrical Conductivity in Utah State Geothermal Wells
14-2 and 52-21**

Depth Interval Feet (meters)		Acoustic Velocity Feet/Sec (Km/sec)	Bulk Density gm/cc	Neutron Porosity %	Resistivity ohm-m
52-21 54	720-920 (220-280)	17,700 (5.4)	Below 720' and throughout the hole length the bulk den- sity varies between 2.5 and 2.8 gm/cc, averaging about 2.65 gm/cc.	Porosity probably varies from close to 0 up to 10%, the highest porosity occurring in fractured rock.	Transition at top of bedrock 30-100 above and 300->1500 below
	920-1500 (280-458)	18,500 (5.7)			
	1500-2600 (458-811)	20,000 (6.1)		Except in obviously fractured intervals, porosity is probably 0 - 2%.	2080-2205 feet (634-888) 40-100; 2205-2910 feet (672-888) highly variable 600->1500; 2910 feet to TD mostly above 1500 but locally as low as 100.
	2660-5420 (811-1690)	22,200 (6.7)			
	5420-TD (1690-TD)	20,000-22,200 (6.7-6.7)			
14-2	600-2200 (183-671)	15,400-17,550 (4.7-5.4)	640-1220:2.58-2.60 1220-1600:2.68-2.70 1600-1800:2.35-2.50 2200 to TD:2.55-2.70	640-1600 feet: the neutron porosity is highly variable and probably inaccurate; 1600-1800: the true porosity is probably close to 15%; 1800 to TD: the log shows a porosity of 1% to 10%, true porosity probably no greater than 6%.	640-840 feet (195-256): the resistivity averages 15 to 25 ohm-m; 840-2080 feet: the resistivity increases uniformly with depth from 40 to 200, averaging about 100 ohm-m; from 2080 feet to TD the log is probably saturated most of time.
	2200-3150 (671-961)	18,300 (5.6)			
	3150-4980 (961-1520)	16,700-17,100 (5.1 - 5.2)			
	4980-TD (1520-TD)	18,200-19,200 (5.5-5.9)			

Figure 8 Logs From Utah State Geothermal Well 52-21

(Plate I). This example illustrates the lithologic influence on the neutron and density logs. Note that the biotite-hornblende quartz monzonite gneiss shows a characteristic high neutron porosity simultaneously with a high bulk density. The density may indeed be higher but the neutron log reflects either the hydrous mineral content or the presence of trace elements which have a large neutron capture cross section.

A detailed analysis of this example and others is given in Glenn and Hulen (1979). Briefly, one can examine the neutron and density log responses in these type of rocks in terms of the heavier, hydrous minerals that are commonly present. The basis for this analysis has been given in an earlier section in a discussion of the crossplot equations and GPC-15.

Figure 9 shows a crossplot of neutron porosity versus bulk density for the interval 5190 to 5310 feet, (1583-1620 meters), in Utah State 52-21. The distinct log response is obvious in Figure 8 and is an interval composed almost entirely of biotite-hornblende quartz monzonite gneiss. The grid in Figure 9 is based on a mafic mineral density of 3.15 gm/cc and volume percent water of 8%. The log response dependence on hydrous mafic mineral content is further demonstrated in Figure 10. The log data have been averaged over 10 foot intervals to correspond to the chip sample intervals. The mafic mineral content, largely biotite and hornblende, has been determined from chip samples by visual estimation using a binocular microscope and by point counting using a petrographic microscope. The data are shown in Table 7. Figure 10 clearly demonstrates the increasing bulk density, neutron porosity and acoustic velocity (decreasing travel time) with increasing mafic mineral content.

Figure 9

UTAH STATE GEOTHERMAL WELL 52-21

TABLE 7: Utah State Well 52-21, Roosevelt Hot Springs KGRA:
5190-5310' (1583-1620m): Selected Mineralogy of Ten-Foot Chip Samples

5190-5200'	15	10	2.0	1.0	Tr.	0.5	Tr.	0.5	0.3	26.5
5200-5210'	17	8	2.0	2.0	Tr.	1.0	Tr.	1.0	0.3	28
5210-5220'	17	8	2.0		Tr.	0.5	0.5	1.5	0.1	26.5
5220-5230'	23	19	2.5	3.0	Tr.			1.0	0.1	46
5230-5240'	30	25	3.0	5.0	Tr.			1.0	0.3	61
5240-5250'	23	19	2.5	3.0	Tr.	Tr.	0.5	1.5	0.1	46.5
5250-5260'	23	19	2.5	3.0	Tr.			0.5	0.3	45.5
5260-5270'	25	15	2.5	2.0	Tr.			1.0	0.1	43
5270-5280'	15	7	1.5	1.0	Tr.		0.5	1.5	0.1	25
5280-5290'	10	5	1.0	3.0	Tr.	0.5	0.5	1.5	0.1	19.5
5290-5300'	4	2	1.0	0.5	Tr.		0.5	0.5	0.1	7
5300-5310'	4	2	1.0	0.5	Tr.		0.5	1.0	0.1	8

However, it also suggests that above approximately 40% by volume of mafic minerals, the acoustic velocity tends to decrease. This observation has been noted in several data plots (Glenn and Hulen, 1979). The increasing rock density with increasing mafic mineral content may control the increasing velocity until some point where higher fractions of platy minerals such as biotite and chlorite cause a decrease in velocity. This effect would be greatest where the platy minerals accumulate on fractures.

Schlumberger's Induction-Electrical Log and Dual Induction-Laterolog 8 were run in 14-2 and 52-21, respectively. Schlumberger recommends not using these tools where the resistivity is above 100 ohm-meters. Low porosity and relatively unfractured igneous and metamorphic rocks, which contain minor amounts of metallic minerals, commonly have much higher resistivities than 100 ohm-meters. Resistivities of less than 100 ohm-meters in restricted intervals of 14-2 and 52-21 are interpreted as being due to one or more of the following: 1) permeable fracture zones saturated with conductive fluid, 2) clay alteration (concentrated in the upper portions of the holes), and 3) sulfide mineralization, particularly if occurring as interconnected veinlets. Thus, low resistivities alone do not necessarily signal potentially productive thermal fluid entries in these holes. Paleo-hydrothermally clay-altered and/or sulfide-bearing zones, for instance, could be relatively conductive while being completely sealed and impermeable. Visual estimates of sulfide content accompany the lithologic columns of Plates I and II.

The resistivity logs are saturated over most of the lower portions of the holes. The lower portion of 52-21 (below about 2200 feet, 671 m) exhibits

greater resistivity variation and contains many more intervals of less than 100 ohm-meters than the lower portion of 14-2 (below about 3000 feet, 915 m, Table 6). The uniformly high resistivity of the lower portion of 14-2 suggests that significant production zones are confined to the upper part of the hole. Further discussion of fluid entries based on log responses follows in the next section.

HEAT FLOW AND FLUID ENTRIES IN UTAH STATE 52-21, 14-2, 72-16, and GPC-15

Some discussions of heat flow at the Roosevelt Hot Springs KGRA have been presented by Sill and Bodell (1977), Ward et al. (1978) and Wilson and Chapman (1980). Only a few comments will be made here and only in terms of the well log data.

Several temperature logs were obtained in each of the four holes studied and the logs were obtained under a variety of conditions. The last temperature logs obtained in drill holes GPC-15, 72-16, and 52-21 depict, quite closely, the true geothermal profile in the vicinity of these holes. The temperature logs in 14-2 may reflect the character of the true gradient, but the hole had probably not reached thermal equilibrium when the last log was obtained. Temperature gradients for 52-21, 72-16, and GPC-15 have been presented and discussed very briefly earlier in this report (Figures 4, 5, and 6).

Changes in the geogradient with depth will reflect the varying thermal conductivity, intersection or proximity of permeable fracture or pore porosity (which are cells of fluid convection or flow), and perturbations due to some thermal event which is no longer active. The rock thermal conductivity is a function of a number of things (Plewa, 1976) including mineralogy, water saturation, porosity, temperature, and pressure. The pressure effects are very small and/or masked. The temperature and mineralogy effects, which can be significant (Clark Jr., 1966; Moiseyenko et al., 1970), are demonstrated in Figure 11. The data plotted in Figure 11 have been taken from Clark Jr. (1966). In general, rocks higher in crystalline silica have a higher thermal conductivity and a greater variation of thermal conductivity with temperature. Figure 11 and

THERMAL CONDUCTIVITY AS A FUNCTION OF TEMPERATURE

Figure 11

the temperature logs and/or the temperature gradient logs in Utah State 52-21, 14-2, 72-16, and GPC-15 suggest that temperature-induced variability in the thermal conductivity is small. The temperature increase with depth should decrease the thermal conductivity, in most rock types, and should increase the gradient. The opposite change in gradient is observed.

Thermal conductivity should increase with decreasing porosity. Plewa's (1976) data for Jurassic limestone indicates a change in thermal conductivity from 8 to 10 m cal/cm-sec-°C (8 to 10 TCU, Thermal Conductivity Unit), a 25% change, over a porosity change of 8% to 0%. The correlation coefficient for this relationship was 0.97. Both of these property ranges are close to those expected for the crystalline rocks encountered in three of the holes studied here.

Fluid saturation can significantly affect the thermal conductivity, but the rocks at Roosevelt Hot Springs KGRA below the upper part of the alluvium are considered to be completely saturated with water. The salinity effect on the water thermal conductivity is not considered to be important here.

The temperature, lithology, and porosity effects on thermal conductivity are probably influencing the temperature logs in 52-21, 14-2, 72-16, and GPC-15 but the most important effect in all four holes, particularly in 14-2 and partly in 72-16, is the influence of intersecting and nearby permeable fracture zones. Goyal (1978) has computed temperature profiles for a two-dimensional radial flow model and for a fault-controlled charging of a geothermal reservoir model. His fault model solutions, developed for the East Mesa Reservoir, mimic the gradients observed in 52-21, 14-2 and 72-16. The fracture in these models is isothermal and the temperature gradients change from vertical near the fault to the true

geothermal gradient some distance from the fault. A clay cap over the reservoir is shown to modify the gradient in the near surface. Drill hole 14-2 is interpreted to intersect and remain close to one or more nearly isothermal fracture zones, and drill hole 72-16 appears to do the same in the upper portion of the hole.

Sill and Bodell (1977) reported an average thermal conductivity of 4.0 mcal/cm-sec-°C (4 TCU) for the alluvium and an average peak heat flow of 40 μ cal/cm²sec (40 HFU) at the Roosevelt Hot Springs KGRA. Wilson and Chapman (1980) report an average 4 TCU thermal conductivity for the alluvium based on a 6 TCU thermal conductivity for the solid material and a 30% porosity. They also report an average peak heat flow of 100 HFU. If we assume the Agnew and Sweet temperature log obtained 3/30/77 is close to the true geothermal gradient and that the thermal conductivity of the alluvium between 150 and 300 feet (46 and 92 meters) is 4 TCU, we obtain a heat flow value of 42 HFU. We can then estimate the following heat flow parameters with depth in Utah State 72-16:

<u>Depth Interval</u>	<u>Temperature Gradient</u>	<u>Thermal Conductivity</u>
feet (meters)	°C/km	cal/cm °C sec
150-300 (46-92)	1050	4 (Sill and Bodell)
300-450 (92-137)	210	20
450-550 (137-168)	425	9.9
550-1200 (168-366)	110	38

While 9.9 TCU may be slightly high for these rocks, 20 and 38 TCU are unrealistic thermal conductivities. These results suggest that convection occurs in the 300-450 (92-137 meters) and 550 to 1200 feet (168-366 meters) depth intervals. These calculations assume only heat conduction in the upper

alluvium interval. Alternatively, if one assumes heat conduction only in the 300 to 450 feet (92-137 meters) interval and a thermal conductivity of 4 TCU, an entirely different result is obtained. Thermal conductivities of .8, 4, 2 and 7.64 TCU are obtained for the same intervals noted above. The .8 TCU value is reasonable for relatively dry, porous alluvium, which may not be dry here, and 7.64 TCU is quite reasonable for the igneous and metamorphic rocks in this drill hole. However, the 2 TCU thermal conductivity obtained for the 450 to 550 feet (137-168 meters) interval is unreasonably low. The heat flow for this second case would be only 8.8 TCU which would be entirely the result of conduction. This value for heat flow in the heart of the geothermal system is much too low. Neither purely conductive nor purely convective heat flow are likely in the vicinity of 72-16, but we favor the first case discussed above where convective heat flow processes are dominant.

Although the latest temperature log in 14-2 probably does not show the true geothermal gradient, the thermal recovery of the hole, as seen in the sequence of temperature logs, suggests that 14-2 is in a region dominated by strongly convective heat flow below 1600 feet (488 meters). The average temperature gradient in the upper part of 14-2, above 1600 feet (488 m), is about 289°C/km (Agnew and Sweet log of 11/15/76). Assuming heat conduction only and a thermal conductivity of 7 TCU, this gradient implies a heat flow of 20 HFU, which is approximately half the value determined for 72-16.

Drill holes 52-21 and GPC-15 have very similar types of geothermal gradients. Both holes exhibit a decreasing gradient with depth and at some point, 5000 feet (1525 meters) in 52-21 and 1200 feet (366 meters) in G-15, the gradients decrease sharply. In 52-21 the gradient actually goes through a reversal between 5100 to 5400 feet (1556 to 1647 meters). In both cases the decreased thermal gradient indicates an intersection with or proximity to a zone of cooler fluid.

If the thermal conductivity of the alluvium in GPC-15 is 4 TCU and the interval 800 to 1200 feet (244-366 m) is in thermal equilibrium and heat flow is purely conductive the heat flow is about 4 HFU. This value is probably low due to the influence of cooler fluid movement below 1200 feet (366 m).

In 52-21, if the same conditions as in GPC-15 above are imposed, the heat flow between 600 and 2200 feet (183 and 671 meters) is about 7 HFU. The gradient in this interval is about $100^{\circ}\text{C}/\text{km}$ and we assumed a thermal conductivity of 7 TCU. Below 7000 feet (2135 meters), which is well below the temperature inversion at 5900 feet (1586 meters), the temperature profile appears to be asymptoting to about $45^{\circ}\text{C}/\text{km}$. Using a thermal conductivity of 8 TCU, this gradient implies a minimum heat flow of 3.6 HFU. Drill hole 52-21 at depth is moving to the south-east and away from what seems to be the center of the geothermal system. Therefore, the change in geothermal gradient reflects not only the intersection or proximity of a cooler zone but also the movement of the drill hole at depth in a direction of expected lower temperatures.

Based on temperature log recoveries, various "porosity" logs, drillers' logs and drill chip mineralogy, we suggest the intervals shown in Table 8 as potential permeable zones; hence, they are potential production zones. Actual production can only be suitably ascertained from production logging and production testing of these zones.

SUMMARY

The log quality in the four drill holes appears to be typical for such a suite of logs. Except for caliper logs, temperature effects do not appear to be severe in any of the holes logged, primarily because the hotter holes were circulated before being logged. Log interpretation is made difficult only for the reason that the logs are calibrated for and recorded in oil field units whereas the primary rocks logged are igneous and metamorphic rocks. Standard interpretation techniques can be used with satisfactory results, but these interpretations would be improved if adequate calibration data existed for these rock types. We believe calibration data are particularly needed for borehole compensated neutron and density tools and for the different types of neutron tools. A different selection of resistivity tools designed to measure resistivities above 100 ohm-m should be considered.

Temperature logs can be tentatively interpreted in terms of heat flow and rock permeability. Both 72-16 and 14-2 are influenced by fracture-controlled convective fluid flow systems. Drill holes GPC-15 and 52-21 exhibit thermal environments influenced by cooler fluid incursion at depth. Heat flow in the vicinity of 72-16 and 14-2 is quite high, 40 and 20 HFU respectively, and in the vicinity of 52-21 and GPC-15 it is much lower, approximately 7 and 4 HFU,

Table 8: Estimate of potential permeable zones in the four holes based on log data.

<u>Drill Hole</u>	<u>Depth Interval</u> feet (meters)	<u>Subjective Permeability Estimates</u> (high, moderate, low)
Utah State 52-21	2000-2400 (610-732) 5200-5900 (1588-1800)	very low very low
Utah State 14-2	various short intervals between 800 and 1400 (244-427) *1600-1800 (488-549) *2850-2925 (869-892) 5400-5800 (1647-1769)	low high high moderate
Utah State 72-16	*300-320 (92-98)** *500-520 (153-159)** *620-650 (189-198)**	high high high
GPC-15	Entire hole	high

*Fluid entry zones of Bamford et al. (1979) correlate all or in part with these intervals.

**May be part of same zone

respectively. The best fluid entries in 72-16 and 14-2 appear to be in the upper parts of the holes. In the case of 72-16, there is some question whether fluid is moving down around casing from a higher level. This possibility should be investigated. Drill hole GPC-15, a thermal gradient test, entirely in alluvium, does not reach a sufficient temperature to be of interest for power generation and drill hole 52-21, although the temperature may be sufficient, does not have sufficient permeability.

All four holes are in quite different lithologies and considerably far apart geographically and in the case of 72-16 very few logs were obtained. Therefore, no attempt has been made to correlate any features among the four holes beyond a comparison, where appropriate, of log responses to particular rock units. The logs could be interpreted in terms of a water table depth, 545 feet (166 meters) and a decreasing porosity and increasing compaction with depth in drill hole GPC-15. The biotite-aplite-porphyry/biotite-microgranite units exhibit high natural gamma counts which we attributed to natural concentrations of potassium in these acidic rocks and to the presence of uranium and thorium, possibly in the minerals zircon and allanite which are present in the rocks. The hydrous mafic minerals, predominantly biotite and hornblende in rock units such as the various gneisses and in particular the biotite hornblende quartz monzonite gneiss, strongly influence the neutron, density and acoustic log responses. The higher density and the contained water of these minerals are the principal properties influencing the log response. Trace element effects are not precluded but have not been investigated. The resistivity logs respond with low resistivities to clay and metallic mineralized fractures. The unfractured rocks exhibit 100 to greater than 1500 ohm-meter resistivities. Induction logs were used and these higher resistivities are either not accurate or are saturation values.

ACKNOWLEDGEMENTS

We thank Doris Cullen, Connie Pixton and John Lopez for drafting the many difficult plates and figures, Sue Moore and her staff for typing the manuscript and John Atwood for his help in digitizing and processing the well log data. We also thank Mike Bullett for his assistance in logging the lithology of GPC-15 and our colleagues who reviewed the manuscript: D.L. Nielson, H.P. Ross, W. R. Wilson and P.M. Wright.

REFERENCES

- Archie, G.E., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics: Trans. AIME, v. 146, p. 54-62.
- Ballantyne, G.H., 1978, Hydrothermal alteration at the Roosevelt Hot Springs thermal area, Utah -- characterization of rock types and alteration in Getty Oil Company Well Utah State 52-21: Univ. of Utah Dept. of Geol. and Geophysics Topical Rept., DOE/DGE Contract No. EG-78-C-07-1701.
- Ballantyne, J.M., and Parry, W.T., 1978, Hydrothermal alteration at the Roosevelt Hot Springs thermal area -- petrographic characterization of the alteration to 2 kilometers in depth: Univ. of Utah Dept. of Geol. and Geophysics Tech. Rept. No. 78-1701-a.1.1., DOE/DGE Contract No. EG-78-C-07-1701.
- Bamford, R.W., Christensen, O.D., and Capuano, R.M., 1979, Multielement geochemistry of solid materials in geothermal systems and its applications: Part I: The hot-water system at the Roosevelt Hot Springs KGRA, Utah: Earth Science Lab., Univ. Utah Res. Inst. rept. no. 30, DOE/DGE Contract DE-AC03-79ET-27002.
- Bodvarsson, G., 1973, Temperature inversions in geothermal systems: Geoexploration, v. 11, no. 2, p. 141-149.
- Clark Jr., S.P., Editor, 1966, Handbook of physical constants: GSA, Yale University, New Haven, Conn., Memoir 97, Section 21, Thermal Conductivity, pp. 459-482.
- Cunningham, R.A., 1978, An empirical approach for relating drilling parameters: Jour. Petr. Techn., p. 987-991.
- Deer, W.A., Howie, R.A., and Zussman, J. 1975, Rock forming minerals, v. 3: John Wiley and Sons, N.Y.
- Edmundson, H., and Ragnier, L.L., 1979, Radioactive logging parameters for common minerals: SPWLA Twentieth Annual Logging Symposium, June, Tulsa, Oklahoma, paper 0.
- Gearhart-Owen Industries, Inc., 1975, Formation evaluation data handbook: Fort Worth, Texas.
- Gertson, R.C., and Smith, R.B., 1979, Interpretation of a seismic refraction profile across the Roosevelt Hot Springs, Utah and vicinity: Univ. Utah, Dept. of Geology and Geophysics, p. 125, DOE/DGE Contract No. DE-AC07-78ET28392.

Glenn, W.E., and Nelson, P.H., 1977, Borehole logging techniques applied to base metal ore deposits: Exploration 77 Symposium, Ottawa, Canada, October, publication in press.

Glenn, W.E., and Hulen, J.B., 1979, A study of well logs from Roosevelt Hot Springs, KGRA, Utah: SPWLA Twentieth Annual Logging Symposium, June, Tulsa, Oklahoma, paper 22.

Goyal, K. P., 1978, Heat and mass transfer in a saturated porous medium with application to geothermal reservoirs, Ph.D. thesis, Dept. of Mech. Engr., Univ. of Colorado, pp. 293.

Hulen, J.B., 1978, Stratigraphy and alteration, 15 shallow thermal gradient holes, Roosevelt Hot Springs KGRA and vicinity, Millard and Beaver Counties, Utah: Univ. of Utah Research Inst., Earth Science Laboratory Rept. 9, DOE/DGE Contract EG-78-C-07-1701.

Lenzer, R.C., Crosby, G.W., and Berge, C.W., 1976, Geothermal exploration of Roosevelt KGRA, Utah: Seventeenth Ann. Symposium on Rock Mechanics (Abs.).

Lipman, P.W., Rowley, P.D., Mehnert, H.H., Evans, S.H., Nash, W.P., and Brown, F.H., 1978, Pleistocene rhyolite of the Mineral Mountains, Utah -- geothermal and archaeological significance: Jour. Research U.S. Geol. Surv., v. 6, no. 1, p. 133-147.

Moiseyenko, U. I., Sokolova, L. S., and Istomin, V. Ye., 1970, Electric and thermal properties of rocks, Nauka Press, Siberian Department, Novosibirsk, NASA Tech. Trans., TT F-671.

Mower, R.W., and Cordova, R.M., 1974, Water resources of the Milford area, Utah, with an emphasis on ground water: Utah Dept. Nat. Resources Tech. Pub. 43.

Nelson, P. H., and Glenn, W. E., 1975, Influence of bound water on the neutron log in mineralized igneous rocks, SPWLA Sixteenth Annual Logging Symposium, New Orleans, Louisiana, June, paper M.

Nielson, D.L., Sibbett, B.S., McKinney, D.B., Hulen, J.B. Moore, J.N., and Samberg, S.M., 1978, Geology of Roosevelt Hot Springs KGRA, Beaver County, Utah: Univ. of Utah Research Inst., Earth Science Laboratory Rept. 12, DOE/DGE Contract EG-78-C-07-1701.

Pickett, G. R., 1973, Pattern recognition as a means of formation evaluation: SPWLA Fourteenth Annual Logging Symposium, May, Lafayette, Louisiana, paper A.

Plewa, S., 1976, Correlation between thermal conductivity and other physical parameters of rocks in KAPG Geophysical Monograph, A. Adam, editor, Akademiai Kiado, Budapest.

Rohrs, D., and Parry, W.T., 1978, Hydrothermal alteration at the Roosevelt Hot Springs thermal area, Utah -- Thermal Power Company well Utah State 72-16: Univ. of Utah Dept. of Geol. and Geophysics Topical Rept., DOE/DGE Contract No. EG-78-C-07-1701.

Schlumberger, 1972, Log interpretation v. I., Schlumberger, Limited, Houston.

Sill, W.R., and Bodell, J., 1977, Thermal gradients and heat flow at Roosevelt Hot Springs: Univ. of Utah Dept. of Geol. and Geophysics, Tech. Rept. 77-3, ERDA Contract No. EY-76-S-07-1601.

Stierman, D. J., and Kovach, R. L., 1979, An in situ velocity study: The Stone Canyon Well, Jour. Geophy. Res. v. 84, No. B2, p. 672-678.

Thermal Power Company, 1977, Geothermal Resources Well Summary Report, copies available from the Earth Science Laboratory, Salt Lake City, Utah.

Timur, A., 1976, Temperature dependence of compressional and shear wave velocities in rocks: SPWLA Seventeenth Annual Logging Symposium, June 9-12, Denver, Colorado, paper A. Also in Geophysics, v. 42, No. 5, p. 950-956.

Ward, S.H., and Sill, W.R., 1976, Dipole-dipole resistivity delineation of the near-surface zone at the Roosevelt Hot Springs area: Univ. of Utah Dept. of Geology and Geophysics, Tech. Rept. 76-1, ERDA Contract No. EY-76-S-07-1601.

Ward, S.H. et al, 1978, A summary of the geology, geochemistry and geophysics of the Roosevelt Hot Springs Thermal Area, Utah, Geophysics, v. 43, No. 7, p. 1515-1542.

Wilson, W. R., and Chapman, D. S., 1980, Thermal studies at Roosevelt Hot Springs, Utah, Univ. of Utah. Tech. Rept., DOE/DGE Contract DE-AC07-78ET-28392.

Wollenburg, H. A., 1976, Radioactivity of geothermal systems: in Second United Nations Symposium on the development and use of geothermal resources, San Francisco, p. 1282-1292.

Wyllie, M. R. J., Gregory, A. R., and Gardner, G. H. F., 1956, Elastic wave velocities in heterogeneous and porous media: Geophysics, v. 21, No. 1, p. 41-70.

_____, 1958, An experimental investigation of factors affecting elastic wave velocities in porous media: Geophysics, v. 23, No. 3, p. 459-493.

EXPLANATION

GENERALIZED DRILL HOLE LITHOLOGY by J.B. Hulen	CORRELATIVE SURFACE LITHOLOGY (Wilson and others, 1978)
PUMICEOUS and PERLITIC ARKOSIC ALLUVIUM - Subrounded to angular, grains up to 10mm (average 2-5mm) in diameter, consisting of Plagioclase feldspar and quartz, fine-grained gneiss and Tertiary granitic intrusive rock.	Qal Quaternary alluvium
ARKOSIC ALLUVIUM - Same as above with only traces of pumice and perlite.	Qal Quaternary alluvium
HORNBLENDE DACITE (ANDESITE?) PORPHYRY - Subvolcanic feature. Micro-crystalline to fine-crystalline. 5-7% biotite, 15-20% hornblende, 0-2% perthite, 5-10% quartz, 5% apatite, 1-2% dark opaque minerals, remainder plagioclase, commonly intensely hydrothermally altered and sulfide-bearing.	Tmd(?) Tertiary microdiorite
BIOTITE-HORNBLENDE MICRODIORITE PORPHYRY - Subvolcanic feature. Micro-crystalline to fine-crystalline. 5-7% biotite, 15-20% hornblende, 0-2% perthite, 5-10% quartz, 5% apatite, 1-2% dark opaque minerals, remainder plagioclase, commonly intensely hydrothermally altered and sulfide-bearing.	Tmd Tertiary microdiorite
LEUCOCRATIC GRANITE AND GRANITIC BANDS and SEGREGATIONS in GNEISS, UNDIVIDED. Fine- to medium-crystalline, generally less than 0.5% biotite to 5% biotite (rarely with traces of hornblende), less than 0.5% dark opaque minerals, traces apatite, zircon, apatite; includes some plagioclase and probable quartz. Minor pegmatite.	Probably Tgr Tertiary fine-grained granite and granitic bands and differentiates in P-Csg (Precambrian banded gneiss)
BIOTITE-HORNBLENDE QUARTZ MONZONITE GNEISS - Generally medium-crystalline, but varies from fine (rare) to coarse-crystalline, variable composition, 7-30% coarse-grained hornblende, 0-20% (average 7%) biotite, 0-2% apatite, 0-1% apatite, trace zircon, 1-5% dark opaque minerals.	PCgn Precambrian hornblende gneiss (may include some hornblende rich layers in P-Csg) (Precambrian banded gneiss)
FELDSPAR-QUARTZ-BIOTITE-HORNBLENDE-STILL-MANTLE GNEISS - Fine- to medium-crystalline, closely to well-foliated, principal constituents occur in highly variable ratios. Biotite varies from 5-30%, hornblende from 0-40%, quartz 40-60%, sillimanite 0-10%, apatite 0-5%, zircon 0-5%, dark opaque minerals, local trace garnet, zircon.	PCg Precambrian banded gneiss

* For more detailed descriptions refer to Wilson and others (1978), Appendix II.

LOG COMPOSITE OF
UTAH STATE GEOTHERMAL WELL
52-21
GETTY OIL COMPANY
ROOSEVELT HOT SPRINGS, KGRA
BEAVER COUNTY, UTAH
NOVEMBER 1978

DRILL HOLE LITHOLOGY by J. N. Moore and J. B. Hulen, 1978	CORRELATIVE SURFACE LITHOLOGY (Nielson & others, 1978)
ARKOSIC ALLUVIUM. Subrounded to angular grains up to 10 mm. (avg. 2-3 mm) in diameter dominated by Tertiary granitic intrusive rocks with minor Precambrian gneiss.	Qal (Quaternary alluvium)
SILICIFIED ARKOSIC ALLUVIUM. Same as above except cemented with a mixture of opal, chalcedony and quartz.	Qcal (Quaternary cemented alluvium)
MICRODIORITE. Intensely hydrothermally altered, subdiabasic texture, microcrystalline to fine-crystalline; 20-25% altered amphibole (w/ minor pyroxene), 65-70% altered plagioclase; remainder quartz, altered orthoclase, leucoxene, apatite, tr. zircon.	Tmd (Tertiary microdiorite)
BIOTITE GRANITE. Leucocratic, fine to medium grained, subequigranular. 50-60% potassium feldspar (microcline plus orthoclase), 15-20% oligoclase, 10-15% quartz, 1% biotite, tr. 0.1% allanite, tr. 0.5% magnetite-ilmenite, local tr. scheelite.	Probably Tgr (Tertiary fine-grained granite) but may include some precambrian banded gneiss.
BIOTITE-HORNBLende QUARTZ MONZONITE GNEISS, medium to coarse grained. 30-35% orthoclase, 1-2% microcline, 20-25% oligoclase, 15-20% hornblende, 15-20% biotite, 2% sphene, 2% magnetite-ilmenite.	Pcgn (Precambrian hornblende gneiss)
BIOTITE-HORNBLende-PLAGIOCLASE-GNEISS, generally fine grained, less commonly medium-grained, 45-50% plagioclase, 5-7% moderately well foliated quartz, 5-7% orthoclase, 10-15% biotite, 15-20% hornblende, 5-7% apatite, 2-3% sphene, 0.1-0.3% zircon, 0.5-1% magnetite-ilmenite.	Pcbg (Precambrian banded gneiss)
FAULT BRECCIA	

LOG COMPOSITE OF
UTAH STATE GEOTHERMAL WELL

72-16

THERMAL POWER CORPORATION
ROOSEVELT HOT SPRINGS, KGRA

LOG COMPOSITE OF THERMAL GRADIENT HOLE GPC 15

GEOTHERMAL POWER COMPANY
ROOSEVELT HOT SPRINGS, KGRA
BEAVER COUNTY, UTAH
JANUARY 1979