A STUDY OF WELL LOGS
FROM COVE FORT-SULPHURDALE KGRA,
MILLARD AND BEAVER COUNTIES, UTAH

MASTER

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July 1982

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

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Prepared for
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ABSTRACT

Union Oil Company drilled four geothermal test wells in the Cove Fort-Sulphurdale KGRA between 1975 and 1979. A fairly complete suite of well logs were recorded for the three deeper holes, and these data are presented as composite well log plots in this report. The composite well log plots have facilitated the interpretation of limestone, dolomite, sandstone, quartz-monzonite, serpentine, and volcanic lithologies and the identification of numerous fractures. This has been especially helpful because of the extensive lost circulation zones and poor cuttings recovery. Intraformational flow was identified by a fluid migration-temperature tracer log at depth in CFSU 31-33.

Well log crossplots were computed to assist in lithologic identification and the determination of physical properties for specific depth intervals in a given hole. The presence of hydrous minerals sometimes results in neutron porosity somewhat higher than the true nonfracture porosity, which is generally less than 4%. Permeability is clearly controlled by fractures. A maximum well temperature of 178.9°C, low flow rates and low probable percent flash indicate these wells are subeconomic for electric generation at present. The well log study has substantially improved our understanding of the reservoir as presently drilled.

INTRODUCTION

The Cove Fort - Sulphurdale Known Geothermal Resource Area (CFS KGRA) is located in Millard and Beaver counties, Utah and has been a site of Union Oil Company geothermal investigations between 1975 and 1979 (Figure 1). The Department of Energy, Division of Geothermal Energy (DOE/DGE) has participated in Union Oil Company's exploration through the Industry Coupled Case Study Program. Geoscience data have been submitted to, and subsequently open filed by, the Earth Science Laboratory Division, University of Utah Research Institute (ESLD/UURI) under this program (Fiore, 1980). The data include various well logs from three drill holes, designated Utah State Geothermal Wells 14-29, 31-33 and 42-7, which are 799 m, 1591 m and 2358 m deep respectively. Mud logs, lithologic logs and open-hole well logs were obtained in all three drill holes. Production logs were obtained in the two deeper drill holes. Copies of all well logs may be obtained from Rocky Mountain Well Log Service in Denver, Colorado. A fourth deep hole, Forminco #1, was drilled prior to Union Oil Company's participation in the Industry Coupled program. DOE/DGE purchased some data from this hole but no well logs had been recorded. Therefore, discussion of Forminco #1 will be limited.

In addition to the basic data packages, Union Oil Company submitted comprehensive summaries of drilling, completion and testing of the wells (Union Oil Company 1978a, b, c and 1979a, b). Moore and Samberg (1979) have provided a detailed surface geologic map, geologic cross sections, lithology logs from drill chips for wells 31-33, 42-7, and Forminco #1, and a discussion of the geologic setting around the CFS KGRA. S.M. Samberg has prepared a lithology log for well 14-29 and it is included in this report. Ross (1979)

has described the results of electrical resistivity surveys over the KGRA.

This work, funded by DOE/DGE, complements and expands earlier geophysical studies done by Union Oil Company (Union Oil Company, 1978a). Bamford and Christensen (1979) and Christensen (pers. comm.) have interpreted results of a multielement geochemical study of drill cuttings from the shallow thermal gradient wells. Cook and others (1980) have published a study of the regional gravity and aeromagnetic data around the CFS KGRA.

This report provides a review of and describes some interpretations of the various well logs obtained in the three wells drilled by Union Oil Company under the Industry Coupled program. The logs are interpreted in terms of geology, fluid flow and the geothermal resource characteristics.

GEOLOGICAL AND GEOPHYSICAL SETTING

A detailed discussion of the geology for the CFS KGRA is given by Moore and Samberg (1979); therefore, only a brief geologic description of the area is included here. The CFS KGRA is situated on the boundary between the Colorado Plateau and Basin and Range Province (Figure 1) and lies within the Pavant Range and the Tushar Mountains.

Surface rocks within the KGRA are predominately lava flows and ash-flow tuffs of late Oligocene to mid-Miocene age in the south and Paleozoic limestone in the north. The volcanic rocks were deposited on faulted sedimentary rocks of Paleozoic to Mesozoic age which were locally metamorphosed and mineralized by Tertiary intrusives.

The Paleozoic rocks extend southward under the volcanic cover which thickens from north to south as a result of both faulting and deposition.

These rocks were intruded by quartz-monzonite stocks during the mid-Tertiary.

Recent rock alteration, which is locally intense, is attributed to the currently active hydrothermal system.

The sedimentary rocks, which are largely Paleozoic carbonates and sandstones and minor amounts of Mesozoic redbeds in the Cove Fort area, were folded and thrust faulted during the Sevier Orogeny. Later erosion produced the Late Cretaceous, Price River Conglomerate that unconformably overlies the Pennsylvanian Oquirrh Formation or Coconino Sandstone within the KGRA. Volcanism began 35 m.y. ago with the eruption of lava flows and breccias from local vents. These rocks are overlain by ash-flow tuffs derived from sources in the Marysvale Volcanic Field to the south and east, and from unknown sources in the Great Basin.

During Miocene time, hypabyssal quartz-monzonite intrusions were emplaced in the volcanic sequence to produce weak base metal mineralization. Basin and Range faulting began in the mid-Miocene and is responsible for most of the present topography. The area remains seismically active (Smith and Sbar, 1974; Olson and Smith, 1976; Schaff, 1981). The Sevier River Formation, an alluvial deposit, and thin, interbedded basalt flows accumulated in depressions created by early Basin and Range faulting and were later offset by north- and northeast-trending Basin and Range faults. Recent volcanic activity has produced the Cove Fort Basalt Field on the western margin of the KGRA during the last 1 m.y.

Moore and Samberg (1979) have recognized north-northeast- and north-trending, high-angle faults and low-angle normal faults in the KGRA. Low-angle normal faults appear to postdate many of the high-angle, mid-Miocene

structures and bound large-scale gravitational glide blocks which cap the central portions of the thermal area in the Tushar Mountains. These faults are important to the understanding of the CFS KGRA resource. Nielson and Moore (1979) argue that these glide blocks locally act as insulating and impermeable caps over deeper convective system at the CFS KGRA.

Faults trending northwest to northeast are associated with recent scarps in the Quaternary alluvium and are the youngest mapped faults in the region. The Cove Fort area continues to be seismically active. Earthquake activity is centered 3 km northeast of Cove Fort and is located less than 5 km deep.

Extensive alteration, widespread hydrothermal activity and contact metamorphism accompanied the mid-Tertiary intrusions of quartz monzonite and associated latite porphyry dikes and stocks. The alteration, which appears to have been fracture controlled, is characterized by sulfide minerals, skarn formation and propylitic alteration of the volcanic rocks. Carbonate rocks in well 42-7 are extensively recrystallized and become increasingly metamorphosed with depth. Well 31-33 intersects rocks only weakly altered. Moore and Samberg (1979) suggested that fluorite deposits north of Cove Fort were related to a younger, but pregeothermal intrusive event. The sulfur deposits in the KGRA postdate the fluorite deposits and are related to the present hydrothermal system. Gypsum, pyrite and marcasite are also found in the native sulfur deposits.

The water table is deep, approximately 400 meters, and only H_2S -bearing gases reach the surface, therefore, no hot springs or sinter deposits are found in the area. The H_2S gives rise to areas of intense acid leaching and small sulfur deposits. Hydrogen sulfide was also encountered just above the

water table in each of the deep drill holes.

The altered areas are located east of Cove Fort, along the north and northeast faults in the southwestern Pavant Range, along the southern edge of the denudation faults in the northern Tushar Mountains and along the northeast-trending Basin and Range fault located northeast of Cove Fort. Alteration is believed to result from surficial oxidation of hydrogen sulfide to sulfuric acid which filters downward, leaching the rocks above the water table.

Union Oil Company obtained temperature measurements in 25 shallow gradient holes, gravity data, a reflection seismic survey (Union Oil Company, 1978a) and both dipole-dipole and Schlumberger electrical resistivity surveys (Phoenix Geophysics Inc., 1976). The Earth Science Laboratory obtained additional dipole-dipole resistivity data and a low-level aeromagnetic survey (Ross, 1979). The department of Geology and Geophysics, University of Utah, completed a detailed gravity survey (Cook and others, 1980). Ross (1979) demonstrated a definite correlation between resistivity and rock type. Fault traces, located beneath the alluvial cover, are characterized by low resistivity values. Despite the deep water table, the near-surface resistivities averaged about 50 ohm-m. Ross (1979) attributed the moderate resistivities to vadose water or perched aquifers. The resistivity data outlined a four square mile low-resistivity area which Ross (1979) associates with the known geothermal system.

Interpretation of geological, geochemical, and geophysical data was presented as a case study by Ross and others (1981).

DRILLING HISTORY AND DRILL HOLE DESCRIPTIONS

Twenty-five shallow temperature gradient holes and four deep test wells were drilled within the CFS KGRA. Data from the gradient holes have been reported by Union Oil Company (1978a). Only two of the four wells , 42-7 and 31-33, reached target depth (Ash and others, 1979) due to severe drilling problems, primarily associated with numerous, uncontrollable lost circulation zones. The basic data for the four holes are shown in Table 1; the locations are shown in Figure 2 with mapped and projected fault traces in the region. Intersection of these faults at depth, among other things, created severe drilling problems.

Data in Table 1 clearly show the high cost of exploration drilling at the CFS KGRA. Two of the four drill holes had to be abandoned and all four holes were far above the average cost per meter for geothermal drilling as indicated by Chappel and others (1979). The costs were high largely because of the lost circulation problems and formation collapse into the borehole. A wide range of lost circulation materials were used: fiber, cellophane, cotton seed hulls, mica, walnut hulls, sodium silicate - calcium chloride and diatomaceous earth (Ash and others, 1979). Lost circulation materials had virtually no effect and cement plugs of a variety of slurry types had only marginal success.

One drilling strategy that seemed to work in some instances was to drill without returns using mud and letting the formation accept the flow, followed by use of aerated mud. Although cuttings were returned when aerated mud was used, this step produced fluids from the formations in excess of surface storage capacity and a return to drilling with mud was required. As a result

Table 1. Basic data for the four test wells at Cove Fort-Sulphurdale KGRA.
(Data from Ash et al., 1979 and Union Oil Co. 1978a,b; 1979a,b)

<u>Drill Hole Name and Spud Date</u>	<u>Depth Drilled (meters)</u>	<u>Average cost per meter</u>	<u>No. of days to drill</u>	<u>Logged</u>	<u>Max. Temp. & depth °C @ m</u>	<u>Fluid Depth meters</u>	<u>TDS @ depth ppm</u>	<u>Hole Status</u>
Forminco #1 7/26/76	320.3	\$1,949	34	NO	ND	ND	ND	Abandoned
*CFSU #42-27 11/29/77	2357.6	\$873	105	YES	178 @ 2231 m	409	9405 4775	17.8 cm liner & tie back, surface T.D.
*CFSU #31-33 5/24/78	1591.4	\$797	64	YES	146 @ 1433 m	427	1320 10,000	Pugged at 792.5 m; 7.3 cm tubing to T.D.
*CFSU #14-29 5/25/79	798.6	\$1,335	45	YES	91 @ 664 m	427	4776	Abandoned

* Also named Utah State Geothermal Wells 42-27, 31-33 and 14-29.
All depths referenced top RKB.

chip samples were either not obtained or were obtained as a highly mixed sample. Lithologic logging became impossible or suspect. Also, drilling with aerated mud created corrosion problems that were unacceptable and uncontrollable. Hole sloughing, which was bad, became a severe problem.

A total of 91 cement plugs were placed in the holes with limited success in an attempt to control lost circulation (Ash and others, 1979). Most severe lost circulation occurred in carbonates, particularly dolomites. Drill strings were observed to drop as much as 9 m in some lost circulation zones, suggesting that the carbonates were cavernous.

Lost circulation occurred almost continuously from near-surface to total depth in Forminco #1. Significant amounts of H_2S were noted and had to be controlled. Sanded dolomites proved to be the most difficult lithology to drill. Lost circulation was so severe that a cement plug, required for hole abandonment, was difficult to set. Nine bales of hay, four sacks of sand, empty paper sacks and chopped burlap were placed at the base of casing before a successful cement plug was emplaced. No well logs were obtained in this hole.

The drilling of well 14-29 was nearly as difficult as Forminco #1, although no sanded dolomite was encountered. Lost circulation was severe and the hole filled with material which could not easily be removed while drilling. High-velocity gel pills were used approximately every 9 m to clean the hole; however, the hole was abandoned at 799.6 m depth.

Lost circulation occurred throughout most of the length of both wells 31-33 and 42-7. With the alternating mud aerated/mud drilling strategy and perseverance in setting cement plugs (19 plugs alone were set in well 31-33

between 376.7 m and 388.9 m), both drill holes reached target depth. Well 31-33 has been plugged back to 792.5 m and a 7.3 cm liner placed in the hole. The hole can be used for future temperature measurements. A fairly complete set of well logs was obtained from both wells. Data from a short production test of well 42-7 was also provided by Union Oil Company and the well remains open with a 17.8 cm liner to total depth. The liner is slotted between 940.0 and 2321.1 m.

WELL LOGS

Introduction

The various open-hole, production and cased-hole well logs obtained in wells 14-29, 31-33 and 42-7 are listed in Tables 2, 3 and 4. The tables contain log type, log date, logging company and logged interval. Also noted are hole and casing depths, the type of fluid in the hole and other information pertaining to the time the logs were obtained. Most of the logs have been digitized at 0.15 m intervals and are shown plotted in Plate I, II and III (in pocket). Lithology, as determined from a study of drill chips, is included for each well. Blank sections in the lithologic logs represent intervals of no returns. Other information such as bit and casing sizes, lost circulation zones and time after circulation is included on each plate. In each case, the wells were circulated and cooled prior to logging. Two logging runs were made in wells 14-29 and 42-7, a single logging run was made in well 31-33.

Mud Logs

Mud logs were supplied by R.F. Smith Corp. for wells 14-29 and 31-33 and

Table 2: Open hole well logs obtained in Utah State Geothermal Well 14-29, Cove Fort-Sulphurdale KGRA

Date	Log Type	Logged Interval (m)	Casing Record (cm)	Hole Depth (m)	Remarks
5/25/79 to	R.F. Smith Geothermal Data Log (Mud Log) - Drilling Rate, Rock Density, Temp. In & Out, Lithology, H ₂ S and CO ₂ .	12.2 - 798.6	50.8 cm to 68.3 34 cm to 378.0 24.5 cm to 633.4	79.2 381.0 634.0	Union Oil Co. also made a Mud Log. Only Drilling Rate Digitized. TD at 798.6m.
6/27/79	Schlumberger Dual Induction - Spherically Focused Log with linear Correlation Log (SP)	378.3 - 633.4	34 cm	381.	$R_m = R_{mf} = 1.1 @ 29.4^\circ\text{C}$ $R_{mc} = 1.68 @ 29.4^\circ\text{C}$ MRT = 49.4°C; water. MRT = 52.8°C; water. Limestone Calib.
	Compensated Neutron - Formation Density with Caliper and Gamma Ray	378.3 - 634.3	"	"	
	Four-Arm High Resolution Continuous Dipmeter -	380.0 - 630.3	"	"	MRT=56.7°C; water.
7/7/79	Schlumberger Temperature Log	67.1 - 747.4	24.5 cm	798.6	3 1/2 hrs after circ. 1 hr.
	" " "	67.1 - 751.0	"	"	after circ. water
	Dual Induction - Spherically Focused Log with linear Correlation Log (SP)	633.7 - 750.4	"	"	$R_m = R_{mf} = 1.22 @ 17.8^\circ\text{C}$ $R_{mc} = 1.68 @ 17.8^\circ\text{C}$ water; MRT = 85.0°C
	Compensated Neutron - Formation Density with Caliper and Gamma Ray	638.7 - 752.3	"	"	water; Limestone Calib. MRT = 90.0°C
	Four-Arm High Resolution Continuous Dipmeter Directional Log.	379.9 - 630.3	"	"	water MRT=92.2°C

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Table 3: Well logs obtained in Utah State Geothermal Well 31-33, Cove Fort-Sulphurdale KGRA

Date	Log Type	Logged Interval (m)	Casing Record (cm)	Hole Depth (m)	Remarks
5/24/78	R.F. Smith Geothermal Data Log (Mud Log) - Drilling to Rate, Rock Density, Temp. In & Out, Lithology, H ₂ S and CO ₂ .	15.9 - 1591.4	50.8 cm to 85.3 34.0 cm to 528.2	91.4 528.5	TD 1591.4 m Only Drilling Rate Rate Digitized.
7/18/78	Schlumberger Temperature Log	15.2 - 1486.8	34 cm	1591.4	water
	Four-Arm High Resolution Continuous Dip Meter-Directional Log	528.8 - 1587.1	"	"	"
	Dual Induction Laterolog with linear correlation log (SP)				water no R _m , R _{mf} and R _{mc} values given MRT=172.2°C.
7/19/78	Schlumberger Temperature Log	12.2 - 1587.1	"	"	water
	Compensated Neutron - Formation Density with Caliper and Gamma Ray	526.1 - 1586.6	"	"	water, MRT=172.2°C
	Geotex Corp. Fluid Migration Survey - Temp. & Spinner	0 - 1586.5	"	"	"

Table 4: Well logs obtained in Utah State Geothermal well 42-7, Cove Fort-Sulphurdale KGRA

Date	Log Type	Logged Interval (m)	Casing Record (cm)	Hole Depth (m)	Remark
11/29/77 to 2/28/78	NL Industries - Mud Log - Drilling Rate, Temp. In & Out, Mud Resist. In & Out, CO ₂ H ₂ S, Lithology.	15.2 - 2365.3	50.8 cm to 76.5 34 cm to 473.1 24.5 cm 410.0 to 1023.2 17.8 cm 940.0 to 2321.0	77.7 474.6 1051.0 2357.6	TD 2357.6 m
2/1/78	Schlumberger - Dual Induction Laterlog 8 with linear correlation log (SP).	463.3 - 1049.7	34 cm	1050.7	R _m = 1.25 @ 16.1°C R _{mc} = 1.32 @ 16.1°C R _{mc} = 1.9 @ 16.1°C
	Compensated Neutron Log with Caliper and Gamma Ray	15.2 - 1044.9	34 cm	1050.7	Fresh Foamed Mud: Sandstone Calibration
	Temperature Log	402.3 - 1050.7	34 cm	1050.7	9 hrs after circ.; Fresh Mud
2/4/78	Schlumberger - Cement Bond Log with Gamma Ray	49.4 - 1010.1	24.5 cm	1050.7	MRT = 161.1°C
	Temperature Log	0 - 932.1	24.5 cm	1050.7	2 hrs. after circ.; water
2/22/78	Dia-Log - Casing Profile Caliper Log	0 - 1023.2	24.5 cm	2295.1	
2/25/78	Gearhart-Owen				
-	Temperature Log				
2/26/78	Temperature Log	1023.5 - 2234.2	24.5 cm	2357.6	RUN #1 water level 399.3 m
	Temperature Log	64.0 - 2231.1	24.5 cm	2357.6	RUN #9, water level 399.3 m
	Temperature Log	64.0 - 2234.2	24.5 cm	2357.6	RUN #10, water level 399.3 m
	Temperature Log	365.8 - 2231.1	24.5 cm	2357.6	RUN #14
2/27/78	Schlumberger - Temperature Log	1023.5 - 2362.2	24.5 cm	2357.6	RUN #14, water level 399.3 m, water injected at 553 gpm. Water, 13 hrs. after circ.

Table 4: (cont.)

Date	Log Type	Logged Interval (m)	Casing Record (cm)	Hole Depth (m)	Remarks
2/28/78	Schlumberger - Borehole Compensated Sonic Log with	1023.5 - 2339.0	24.5 cm	2357.6	MRT = 168.9°C; water 4 1/2 hrs after circ.
	Compensated Neutron Formation Density with Calliper and Gamma Ray	1023.5 - 2340.6	24.5 cm	2357.6	Limestone Calib. MRT = 170.0°C, 9 1/2 hrs.
	Dual Induction - Laterlog 8 with linear Correlation log (SP)	1023.5 - 1049.7	24.5 cm	2357.6	$R_m = R_{mf} = 1.29$, @ 17.2°C MRT = 166.7°C
3/1/78	Schlumberger - Four-Arm High Resolution Continuous Dipmeter and Directional Log	1021.1 - 1829.7	24.5 cm	2357.6	Did not log to TD because of temperature. 5 1/2 hrs. after circ. MRT = 170.0°C
5/15/78	Gearhart-Owen - Differential Temperature Log	30.5 - 1841.0	17.8 cm	2357.6	RUN #1, Fluid level 387.1 m 3394 B/D Injection
	Differential Temperature Log	365.8 - 2109.2	17.8 cm	2357.6	RUN #2, after flow stopped.
	Injection Profile Survey (Radioactive Fluid Velocity and Spinner Logs).	914.0 - 2042.2	17.8 cm	2357.6	3394 B/D Injection.

by NL Industries for well 42-7. The mud logs recorded density, drilling rate, in and out flow line temperature and pressure, carbon dioxide and hydrogen sulfide concentrations. Density and pressure were not recorded in well 42-7 but in and out temperature was recorded. Only the drilling rate has been digitized and is plotted for each hole in the respective figures. Many of the other data records are intermittent because of lost circulation. The mud logs provide a good record of drilling problems, lost circulation zones, mud control and bit changes.

Lithology Logs

The lithology logs are shown in Plates I, II, and III. Large gaps in the lithologic logs occur as a result of severe lost circulation and a loss of returns. Also, the alternating method of using mud and getting no returns and by using aerated mud and getting both returns and formation fluid resulted in either no samples or mixed samples. Therefore, the lithologic logs are both incomplete and, in many intervals, suspect. The use of well logs to more accurately pick formation boundaries and identify lithologies under these circumstances is important and will be demonstrated in the next section.

All four holes intersected less than 30 m of Quaternary alluvium, derived from surface rocks in the area; Lower Bullion Canyon volcanics and the Price River Conglomerate. Below the alluvium, well 42-7 intersected almost 600 m of Tertiary volcanics whereas the other three holes intersected less than 300 m of the volcanics.

Wells 14-29 and 31-33 intersected a thin section of Cretaceous Price River Conglomerate, Kpr. Beneath the Tertiary volcanics in Forminco #1 and well 42-7 and the Kpr in wells 14-29 and 31-33, each drill hole intersected

Paleozoic rocks beginning with the Coconino sandstone and followed by the Pakoon limestone which contains chert and dolomite. Forminco #1 bottomed in this unit which, in the area of this drill hole was largely a sanded dolomite. The other three drill holes intersected interbedded, Paleozoic limestone, dolomite and siltstone which have not been differentiated. In well 42-7 some units have been metamorphosed to quartzite and marble. Metamorphism recrystallized the carbonates, and it produced talc in the upper part of the section and fosterite which is entirely serpentized near the base of the section. Dikes of Tertiary quartz-monzonite were intersected in the lower portion of well 42-7 and thin skarn zones occur along the intrusive - sedimentary rock contacts.

Well 31-33 intersected Triassic dolomite, limestone and siltstone beds which have not been differentiated. A pre-volcanic thrust fault (Moore and Samberg, 1979) separates the Paleozoic rocks above from the Mesozoic rocks below. The fault is located at 945.0 m depth. Weak metamorphism is evident in the lower portion of 31-33 by the presence of chlorite in the calcareous siltstones.

The low-angle normal fault zones are believed to occur at the base of the Tertiary volcanics in wells 42-7 and 31-33. Other fracture or fault intercepts may occur in intervals of severe lost circulation. Older fractures and faults may be partially or completely sealed with sulfides, quartz, calcite and anhydrite. An interpretation of these fracture intercepts is made later using well log data.

Open-Hole Logs

Temperature logs: Temperature logging is obviously important in

geothermal exploration. Since high temperatures are a key aspect of the target, it is important to measure temperature accurately and after the borehole has equilibrated. The drill hole and surrounding formations are cooled by the circulating mud during drilling and require some time to return to the equilibrium profile. Hence, most temperature logs obtained during routine open-hole logging operations reflect disturbed temperature profiles. Most often, cold water is circulated in the wells to cool them for protection of logging tools; consequently, temperature logs will reflect the subsequent temperature recovery and can be interpreted, qualitatively, in the manner of temperature injection logs. Two Schlumberger temperature logs were obtained in both well 14-29 and 31-33 and three were obtained in well 42-7. None of the logs were obtained more than 13 hours after circulation. These logs are noted in Tables 2 through 4 and are plotted in Plates I, II and III. The maximum temperature recorded in well 31-33 was 146°C. The bottom-hole temperature, also the maximum temperature for well 42-7, recorded on the logs was 178.9°C. Additional temperature logs were obtained in wells 31-33 and 42-7 and will be discussed under production logs. The log interpretations will be discussed in a later section.

Caliper logs: Caliper logs obtained in all three drill holes were recorded with the compensated neutron and density logs. Since the tool is decentralized, the caliper often depicts a smoother hole than actually exists. Also, this tool tends to cut any mudcake that might be present and mudcake thickness can not be determined. Casing inside diameter and bit sizes used in each hole are sketched in the caliper log column of each log composite. A comparison can be made between the caliper logs and the nominal hole size at

the time of logging. Smooth borehole sections with good returns should have a diameter close to bit size.

Caliper data recorded on high-resolution dip meter logs recorded in the three holes were not digitized.

Acoustic logs: A Schlumberger borehole compensated sonic log (BHC) was recorded in well 42-7; no other acoustic logs were recorded in this or other drill holes. A gamma ray log was recorded simultaneously. The tool was pulled at 18.3 m/sec. Cycle skipping is present at a few locations on the log. The digitized and plotted logs in Plate III may not fully reflect the character of the logs in intervals of cycle skipping. Examples of cycle skipping events are noted on Plate III.

Neutron logs: Schlumberger compensated neutron logs (CNL) were obtained in all three drill holes. Logging speeds were not recorded. The 2/1/78 log obtained in well 42-7 was recorded in sandstone units while a limestone calibration was used on the remaining logs in well 42-7 and on logs in wells 14-29 and 31-33. The 2/1/77 CNL in well 42-7 was logged in foamed mud and all other logs were recorded in water.

Density logs: A Schlumberger compensated density log (FDC) was run simultaneously with the neutron log in each case except in well 42-7 on 2/1/78. A density porosity was printed along each log using a limestone grain density of 2.71 gm/cc and a fluid density of 1 gm/cc. Automatic borehole corrections were used for each log. The density logs were all digitized and are all plotted on Plates I, II, and III.

Electric/Spontaneous Potential logs: Schlumberger Dual Induction - Laterolog 8 (DIL/LL8) with a linear correlation log were obtained in wells

31-33 and 42-7 and a Dual Induction - Spherically Focused log (DIL/SFL) with a linear correlation log was obtained in well 14-29. A spontaneous potential (SP) log was recorded on each log in wells 14-29 and 42-7. A gamma ray log was recorded instead in well 31-33. The resistivity scales, the mud cake, mud filtrate and mud resistivities recorded on the log heading are noted in Tables 2 through 4. The mud cake resistivity was calculated in each case.

The resistivity logs, particularly the deep induction log, are saturated for most of the borehole length below approximately 1280 m in well 42-7. The induction log has this problem in resistive formations.

Gamma-Ray logs: Schlumberger gamma ray logs were obtained with the DIL/LL8 in well 31-33 and with the CNL in all three drill holes. The logs were recorded in API units. The logs were run at 9.15 m/min and a time constant of 2 sec. in wells 14-29 and 42-7 and at 9.15 m/min and a time constant of 1 sec. in well 31-33. A gamma ray log was also recorded with the BHC sonic log in well 42-7; the log was obtained at 18.3 m/min and a time constant of 1 sec. The two gamma ray logs obtained with the CNL and the BHC logs in well 42-7 agree quite closely. Therefore, only one of them, the BHC-GR, is included on the log composite (Plate III).

Dipmeter logs: A Schlumberger Four-Arm High Resolution Continuous Dipmeter log was obtained in all three drill holes. Hole deviation was also calculated and plotted as a Directional log. The hole deviation survey results for wells 14-29, 31-33 and 42-7 are plotted in Figure 3. The Dipmeter logs and computed arrow and stick plots were submitted to ESLD/UURI by Union Oil Company and copies are available from Rocky Mountain Well Log Services, Denver Colorado.

Production and Cased-Hole Logs

No production and cased-hole logs were obtained in wells 14-29 and Forminco #1; both bore holes were plugged and abandoned. Only a single fluid migration, temperature tracer log, operated by Geotex Corporation, was run in well 31-33. The log indicated 10 to 20 bbl/m flow downhole below 1524.0 m depth (approximately) and 704 to 768 bbl/m flow moving up hole above 1448 m depth (approximately). Well 31-33 was subsequently plugged back to 792.5 m to isolate these intraformational flow zones.

A cement bond log, Schlumberger CBL-VDL, was run inside casing in well 42-7 after installation and cementation of the 24.5 cm casing. The log indicates a fairly good bond below 973.5 m depth and between 466.3 m and 606.6 m depths for the 24.5 cm casing. A Dia-Log Company casing profile caliper log was run inside casing in well 42-7 after the drill hole reached 2298.8 m on 2/23/78. The log indicates only 50% of the 24.5 cm casing well thickness remains between 552.9 m and 553.2 m depths. Well loss thickness is 5% to 21% in the remaining length of 24.5 cm casing. The corrosion of the 34.0 cm casing was 9.5% to 17.8%. The corrosion problems and treatments have been discussed at length by Ash and others (1979).

Several production logs were obtained in well 42-7 (Table 4). Six Gearhart-Owen temperature logs were run between 2/25/78 and 2/27/78. These logs are plotted on Figure 5. The logs were obtained in conjunction with either flow from or injection into well 42-7. Gearhart-Owen radioactive tracer and spinner surveys were made in conjunction with a nitrogen assisted flow test between 5/16/78 and 5/17/78. Temperature recovery logs were run on 5/18/78 and 5/19/78. The 17.8 cm slotted liner was in the drill hole during

the flow test. The slotted intervals and per cent of total flow are listed in Table 5 (from Union Oil Company, 1978b).

Table 5: Slotted Intervals in the 17.8 cm liner and per cent of total flow determined from production logging in well 42-7 on 5/15/79.

<u>Slotted Interval (m)</u>	<u>Per Cent Total Flow</u>
1326.8 - 1363.4	51
1481.3 - 1520.7	3
1558.1 - 1621.2	20
1686.8 - 1725.2	13
below 1767.8	13

No tracer shots were made below 1767.8 m due to temperature limitations of the tool. The spinner tool failed to operate satisfactorily. The temperature pressure fall-off and build-up data were measured with Kuster tools and noted as Union Oil Company logs.

The well was produced for 13 hours using nitrogen for the first 6 hours. The flow of 21,818 kg/hr at the end of nitrogen lift period decreased to 19,546 kg/hr at the end of the test. Wellhead pressure was about 3 psig. Shortly after shut-in and release of a non-condensable gas head, the wellhead pressure dropped to 0 psig. The second temperature log, 12 hours after shut-in, indicated a maximum temperature of 171.1°C at 1862.3 m depth and a 168.9°C temperature at 2103.1 m depth. Fluid level was noted at 387.1 m depth.

Summary

Except for a mud log, no well logs were obtained in Forminco #1 which was

drilled prior to DOE/DGE participation with Union Oil Company at the CFS KGRA.

The mud log is available through Rocky Mountain Well log Service in Denver, Colorado. A lithologic log, based on a detailed study of drill chip samples, is presented in Moore and Samberg (1979).

A fairly complete set of open-hole logs were obtained in well 14-29, between 378.3 m and 751.0 m depths, approximately. Logs obtained include neutron porosity, bulk density, gamma ray, temperature, caliper, dip meter and resistivity/SP. Only the temperature logs continue to the surface. No tool failures were reported and maximum temperatures encountered were 92.2°C. No production or cased hole logs were obtained in 14-29.

The same set of open hole logs were obtained in Utah State Geothermal Well 31-33 as listed above for 14-29. Except for temperature logs which begin at the surface, the logged interval is 528.8 m to 1586.8 m, between the bottom of casing and a few meters above total depth. The only tool failure reported was a temperature tool which was successful on a second attempt. The maximum temperature recorded during logging was 146°C. A fluid migration - temperature tracer log was the only production log run in well 31-33. The log did reveal both up and down hole flow which led to plugging back the hole to 792.5 m to seal these zones of intraformational flow. No cased hole logs were run in well 31-33.

In addition to the suite of open-hole logs described above for wells 14-29 and 31-33, an acoustic log was obtained in well 42-7. No tool failures were reported and the maximum temperature encountered during logging was 178.9°C.

A number of production temperature logs, spinner and fluid tracer logs

and discrete pressure and temperature logs during a flow test were obtained in well 42-7. The spinner tool failed to operate and the tracer log was limited to 1767.8 m maximum well depth because of temperature and pressure limitations of the tool. The temperature measurements were quite good and the data suggest a nearly isothermal geothermal reservoir and a large intraformational flow in the borehole.

WELL LOG INTERPRETATIONS

Lithology - Well Log Correlations

Alluvium and Bullion Canyon Volcanics: A gamma ray, neutron and cement bond log in well 42-7 are the only well logs obtained within the alluvium and the Bullion Canyon Volcanics. Of these logs, only the gamma ray log is plotted on Plate III. The alluvium produces a uniform 105 API unit (uncorrected for casing, hole size and cement) gamma ray log. The log does not indicate the contact with the Bullion Canyon Volcanics at 30.5 m, that result suggests the alluvium consists largely of eroded Bullion Canyon Volcanics.

The offset in the gamma ray log at 76.2 m may be entirely due to the cemented, 50.8 cm casing to that depth in the drill hole and the 34.6 cm casing and mud annulus between the two sets of casing. The gamma ray offset between 399.3 m and 473.1 m depth probably marks the cemented portion of the 34.6 cm casing.

Below casing at 473.1 m, the Gamma Ray log remains fairly uniform, about 105 API units. The drift in gamma ray log at this point is, in part, due to the larger hole size. The hole size increase at 620 m corresponds to a fault

noted by Moore and Samberg (1979). The gamma ray log suggests that the base of the Bullion Canyon Volcanics is located at 620.0 m. From the various logs, it appears that the drill hole follows this fault for 45.7 to 76.2 m. The data suggest that the fault is nearly vertical with volcanics on one side and Cocnino sandstone on the other side. This interpretation is suggested by the mixed chip samples over this interval. The hole is undoubtedly close to the fault for some distance above and below the intercept since lost circulation occurs between 423 m and 1051 m.

Triassic Sedimentary Rocks: Moore and Samberg (1977) have reported Triassic sedimentary rocks only in well 31-33. They believe these rocks have been overthrust by older Paleozoic sedimentary rocks. In well 31-33 the undifferentiated Paleozoic rocks largely dolomite, overlie an interbedded sequence of Triassic siltstones and carbonates. The Triassic rocks are distinguished from petrologically similar Paleozoic rocks by their distinct red color. Moore and Samberg's (1979) red silstone in well 31-33 between 954.0 m and 1018.0 m is actually a slightly silty shale. Large gaps in the chip samples due to lost circulation problems made lithologic identification difficult. The lithologic log on Plate II suggests some of the Triassic section is repeated in well 31-33 either by thrust faulting or by uplift and normal faulted slide blocks. Also, parts of the section are missing in well 31-33. The rocks are tentatively identified as Moenkopi Formation.

A very distinct change in each well log on Plate II occurs at 842.8 m depth in well 31-33. The caliper log shows a long interval, 841.2 to 880.9 m hole enlargement, the neutron log shifts from a rather uniform porosity of about 1% average to highly variable porosities between zero and an average of

15%. The bulk density drops from about 2.81 gm/cc to 2.77 gm/cc; the resistivity (R_{ILD}) drops from an average of 74 ohm-m to an average of 33 ohm-m and the gamma ray increases from a fairly uniform 30 API units to a quite variable 35 to 140 API units with an average about 100 API units. The chip samples at and near this depth were either lost or mixed. However, the rock units above and below this depth appear to change from a fairly clean, thick, uniform dolomite above to a series of interbedded siltstones, limestones and dolomites below. In some intervals the carbonates are either argillaceous or arenaceous. The variability of each log below 842.8 m reflects the siltstone-carbonate bedding. The siltstones have a higher gamma ray value, lower neutron porosity, and lower density and resistivity. These responses can be attributed to the presence of clay and sulfide minerals or to carbonaceous material in the siltstones. Darker grey limestone intervals have similar log responses.

The Schlumberger Dip Meter results reveal an abrupt change from random strike and dip determination above 847.3 m to quite uniform north to north-east striking, 30°-40° dipping formation attitude determinations. Unfortunately the log begins at a depth of 533.4 m and attitudes of bedding in the upper part of the hole are unknown.

These data suggest that a major fault, probably a thrust fault, has been intersected by well 31-33 between depths of 841.2 and 880.9 m. The drill hole either paralleled the fault over this distance and actually crossed the fault at 842.9 m or the footwall of the fault is more fractured. The second interpretation may be correct since for the hole to parallel the fault for 30 or more meters would imply a steeper fault than expected for a thrust fault.

Below 1030.2 m the formation dips change slightly to 20 to 30 degrees which may indicate another fault intercept. Additional fault intercepts are indicated by several logs at approximately 1082 m and 1459 m. The fault intercept noted by Moore and Samberg (1979) at 954.0 m is indicated by a 10 to 15 m zone of decreased gamma ray and neutron porosity and increased resistivity. The logs suggest a thin carbonate layer without increased porosity.

Paleozoic rocks: Except for the Permian Pakoon Limestone and Coconino sandstone, the Paleozoic rocks have not been differentiated by Moore and Samberg (1979). The intercepts in wells 14-29 and 31-33 are largely dolomites and probably the same unit. Hintze (1979) shows several dolomite units in the Cove Fort area between late Ordovician and early Permian age. The total thickness, corrected for dip, intersected in well 31-33 indicates at least two of the dolomite formations are present. These formations tend to have a fairly uniform log response, low gamma ray of 10 to 50 API units with an average about 30 API units. Bulk densities tend to be that expected for low porosity dolomites, 2.78 to 2.84 gm/cc with an average about 2.81 gm/cc. The resistivity (R_{ILD}) tends to average about 75 ohm-m.

The Permian Coconino sandstone and Pakoon Limestone, which has lower sandstone member, were intersected only in well 42-7 (Plate III). As noted earlier, the Coconino sandstone is separated from the overlying Bullion Canyon Volcanics by a dipping fault.

The Coconino sandstone and limestone member of the Pakoon Limestone have a gamma ray response between 20 and 50 API units averaging about 30 API units. The sandstone member of the Pakoon Limestone has a higher gamma ray response

of about 125 API units. The neutron log response tends to be dominated by fractures and does not appear to have significant correlation to the lithology, but the resistivity log shows a well-defined decrease to approximately 10 ohm-m.

The caliper, neutron and resistivity logs and the lost circulation problems indicate a significant number of fractures occur in the upper section of Paleozoic rocks in well 42-7. The resistivity log exhibits a strong gradient, an increasing resistivity with depth between 716.3 m and 1435.6 m that may indicate the closing of fractures and/or decreasing of porosity over this depth interval. This resistivity gradient ends at or near the top of the first appearance of metamorphosed sedimentary rocks (marble) in well 42-7. The density log has a less distinct but parallel gradient over the same interval.

The marble which occurs between 1219.2 m and 2118.4 m depth has a uniformly high resistivity of 178 ohm-m (R_{ILD}) or greater. The induction log accuracy decreases above 100 ohm-m (Schlumberger, 1972). In fact the medium induction resistivity is saturated throughout most of the marble intercept. Curiously, the laterolog resistivity is also saturated throughout the same interval. One possible explanation is that drilling mud invaded the formation, filling the pore space, and it was dehydrated (altered) by the high temperatures. The altered mud would be more resistive. The deep induction log is sensing the true resistivity of the fluid-filled porosity behind the invaded zone. Alternatively, larger fractures, such as seen between 1726.7 m and 1749.6 m, remained open after drilling and respond similarly and with a low resistivity on all three resistivity logs. Therefore, the longer spaced,

deep induction log responds to the lower resistivity, widely spaced fractures whereas the short-spaced systems respond primarily to the unfractured, resistive intervals between fractures.

The density log indicates a step-wise decreasing density with depth in the marble that may be attributed to introduction of more silica into the carbonate with depth. Several intercepts of the quartz-monzonite intrusive are located in the marble and there is a close association of lower density either within the intrusive itself or in the marble adjacent to the intrusive. Of course, fractured intervals such as noted earlier between 1726.7 m and 1749.6 m exhibit anomalously lower densities. The acoustic velocity exhibits significant variability in the marble from 5.5 to 6.9 km/sec.

The serpentine marble located below 2161.0 m in well 42-7 has a lower resistivity, higher gamma ray value, lower density and lower acoustic velocity than the marble. Serpentine has a density anywhere from 2.2 gm/cc for the fibrous variety to 2.65 gm/cc for the massive variety. The serpentine itself can explain the main differences observed in the log responses between the marble and the serpentine marble. Serpentine is a hydrous magnesium silicate that may have as much as 33% volume per cent water which would produce an apparent neutron porosity. If inappropriate grain density is used with the bulk density values, a density porosity also in error, could be calculated that would compare to the neutron porosity. The only significant porosity that occurs in the serpentine marble is associated with fractures. The fracture intercepts are clearly defined by the caliper and sonic logs and to a lesser extent by the other logs. One example is located at a depth of 2234.2 m. Dip meter data in wells 14-29 and 42-7 are less useful than those obtained

in well 31-33.

One interesting feature of the gamma ray log is the higher values opposite fracture intercepts in the marble and the serpentine marble. These higher values may be partly due to the presence of potassium alteration minerals and partly due to deposition of uranium on previously or presently permeable fractures. The increased gamma ray occurs at or near the intrusive quartz-monzonite.

Quartz-monzonite: The quartz-monzonite intrusive is intersected in several short intervals between 1880.6 m and 2161.0 m in well 42-7. Other intercepts in this interval are possible but were not noted due to no returns in lost circulation intervals. As noted earlier, the intrusive has a conspicuously higher gamma ray response than does the marble which it intrudes. Therefore, the higher gamma ray intervals observed between 1880.6 m and 2161.0 m are attributed to either drill hole intercepts of the intrusive or near misses of the intrusive. The higher gamma ray values opposite the serpentine marble can be attributed to alteration minerals introduced into the marble by the quartz-monzonite intrusive. The intrusive also appears to be associated with fractured intervals such as between 1871.5 m and 1898.9 m. The intrusive most likely intruded along fractures or faults that have since been reactivated.

Rock Properties

In the previous discussion of the various rock units, some rock property values for each unit were noted. A summary of the various properties as determined from the well log data is given in Table 6. Several crossplots are presented to illustrate the interpretation of the log data and to provide some

Table 6: Rock Property Estimates From Well Logs: Range, Average.

<u>Rock Unit</u>	<u>Gamma Ray API Units</u>	<u>Porosity %</u>	<u>Bulk Density gm/cc</u>	<u>Resistivity ohm-m</u>	<u>Acoustic/Velo. km/sec</u>
Alluvium	no data	no data	no data	no data	no data
Bullion Canyon Volcanics	80-130; 105	15-25; 20	no data	10-30; 15	no data
Triassic Sedimentary Rocks					
Dolomite	30-140; 80	1 - 4	2.70-2.85; 2.77	18-64; 40	no data
Shale	90-150; 110	1 - 4	2.67-2.85; 2.76	12-30; 20	no data
Limestone	35-130; 90	1 - 4	2.65-2.83; 2.74	15-80; 35	no data
Permian Sedimentary Rocks					
Coconino Sandstone	20-50; 30	2-15; 8	no data	6-80	no data
Pakoon Limestone					
Limestone	20-50; 30	no data	no data	3-25	no data
Sandstone	105-145; 125	no data	no data		no data
Paleozoic Rocks, Undifferentiated					
Dolomite	20-50; 30	0-2	2.78-2.95; 2.85	40-150; 75	
Limestone	20-100; 40	undetermined	no data	undetermined	undetermined
Quartzite	50-160	1-6; 2	2.50-2.65; 2.61	no data	no data
Metamorphic Rocks					
Marble	10-120	1-7; 2	~2.65	125-250; 190	5.0-6.9
Serpentine Marble	1-280	1-4; 2	~2.58	40-225; 90	5.0-6.1
Intrusive Rocks					
Quartz Monzonite	110-160	undetermined	~2.65	~190	~6.1

detailed information on several rock units.

Crossplots of gamma ray data versus bulk density and neutron porosity for the depth interval 536.5 m to 1578.9 m in well 31-33 are shown in Figures 4(a) and 4(b), respectively. Both figures demonstrate a strong correlation, as indicated by the straight lines in each figure, between the gamma ray data and bulk density and neutron porosity. An increase in gamma ray response is, in most instances, accompanied by a decrease in density and an increase in neutron porosity. The data reflect, as indicated in the figures by labels, the different responses of the carbonate and the siltstone and the presence of silty and probably shaley carbonate, primarily silty limestone. The logs suggests the limestone below 1250.0 m in 31-33 is more silty than indicated on the lithologic log.

The bulk density and neutron porosity data for the same interval are plotted in Figure 5. The Schlumberger porosity calibration curves for the CNL-FDC tools in dolomite, limestone and sandstone are sketched in the figure. As the geology would suggest, most of the data lie close to the limestone curve and indicate a possible porosity variation of about 0 to 10%. However, a significant trend in the data (as noted by the arrow in Figure 5) indicates increasing dolomite in the limestone at nearly constant porosity of 4% to 5%. The porosity appears bimodal at 0% to 1% and 4% to 5%. However, the higher porosity is probably in part due to hydrous minerals in the silt. If the hydrous minerals are 30% to 40% by volume water, then these data indicate 5% to 10% hydrous minerals present in the siltstone. The true porosity in all rock units varies between 0% and 3%, which increases locally in fractured intervals. An approximate porosity correction for temperature could be made

on these data to give a porosity range 2% to 5%. Additional plots are shown in Figure 6 where the temperature correction to the neutron log data is indicated for data falling in the dotted region. The Schlumberger (1978) calibration lines for dolomite, limestone and sandstone rock types are sketched in Figure 6. However, these plots are for well 42-7 in an interval of recrystallized siltstone, limestone and dolomite (see Plate III). Although the calibration lines can not be viewed as exact, they do confirm the mixed lithology of the interval and that limestone (marble) is the dominant rock type. The plots confirm the low porosity of the rock units.

Figure 6 shows three crossplots of resistivity versus neutron porosity; data from two intervals in well 31-33 and one interval in well 42-7 are plotted. A line is sketched in each figure and is derived from Archie's Law with m equal to 2 and R_w values between 0.085 ohm-m and 0.20 ohm-m. The data are interesting since Archie's Law seems valid only above 4% to 5% neutron porosity. It is possible that small cracks containing conductive clay and metallic minerals contribute to lower resistivity at very low porosities. Moore and Samberg (1979) have logged significant amounts of both mineral types in these drill holes. The fractures also contribute to a lower resistivity on the geometric scale of the induction tool (approximately 1 m) and not to an increased porosity on the scale of the neutron tool (approximately .4 m).

Figure 7 shows a crossplot of resistivity versus SP for two intervals in well 14-29. The three principal components of SP in drill holes are: 1) ionic diffusion potential, 2) streaming potential and 3) oxidation-reduction potential. The first is due to an ionic concentration gradient and the second is due to a pressure gradient between the borehole fluid and the formation.

The third is due to chemical reactions occurring in and around the borehole.

In most drilling situations the first one is the dominant process. The relationship between SP and diffusion potential for low dissolved ion concentrations is:

$$SP = K \log \frac{R_{mf}}{R_w} ,$$

where K is a constant, R_{mf} and R_w are the resistivities of the mud filtrate and formation water, respectively. Using Archie's Law, this expression can be rewritten as

$$SP = K \log \frac{R_{mf}}{R_o} m$$

$$SP = K \log R_{mf} - K \log R_o - mK \log \phi .$$

For constant R_{mf}, M, and ϕ , the SP should have a straight-line relationship to R_o on a semi-log plot, which is observed in Figure 7. Other intervals in these wells do not demonstrate this relationship. The intervals that do demonstrate this relationship may yield valid interpretations from SP and Archie's Law methods whereas intervals that do not display this relationship may not yield valid results from these methods.

Fluid Flow Measurements

Union Oil Company (1979a, b) made considerable effort to determine reservoir properties at Cove Fort-Sulphurdale. Most testing was done in well 42-7 with no test conducted in either well 14-29 or Forminco #1. Tests conducted in well 31-33 were limited to production logging.

The severe lost circulation and cementing problems encountered in drilling all the geothermal wells is indicative of a very permeable reservoir. The significant fluid production from the subsurface while drilling with aerated mud marked the potential for a good reservoir. Hence, Union Oil Company's objectives were to ascertain the reservoir properties including temperature and whether the wells could flow unassisted.

The production logging tests in well 31-33 consisted of temperature injection profiling, pressure gradient surveying, and spinner and tracer logging. These tests revealed significant permeability and fluid production about 1463.0 m to 1524.0 m that moved uphole at a rate of 500 bbl/hr and exited about 612.7 m and moved downhole at 10 to 20 bbl/hr and exited at 1571.2 m. This strong intraformational flow and an indication from temperature logging of cooler fluid entry at the bottom of the hole prompted the plugging of the hole back to 792.5 m.

A variety of temperature injection and production profiling and spinner and tracer logging was done in well 42-7 (Maassen, 1978). Also, a flow test using nitrogen lift was conducted in well 42-7 on 5/16/78. The production test was followed by an injection test on 5/17/78. Flow was initiated using nitrogen lift and later flowed unassisted at a stabilized flow of 19,546 kg/hr and a wellhead pressure of 3 psi. After shut-in and release of a non-condensable gas head, the wellhead pressure dropped to 0 psi. The wellhead temperature was about 200°F (92.3°C). Given this flow rate, temperature and probable percent flash, the well was deemed non-commercial. Since well 42-7 was the best well drilled, the geothermal resource for electric power generation was considered non-economic.

Summary

The well logs clearly delineated several fractured intervals in the Cove Fort-Sulphurdale geothermal wells and their control of fluid flow. The nearly isothermal temperature regime identified in each well suggests a strongly convective system. Part of this temperature profile can be attributed to intraformation flow through the borehole.

The structures controlled drilling as evidenced by the drillers' log report of bits dropping several meters in places, the difficulty in plugging lost circulation zones and the westward drift of all holes (Figure 3), and the downdip direction of most major surface structures mapped in the area.

The well log data crossplots allowed determination of lithology and an estimate of porosity. Non-fracture porosity is generally less than 4%. Permeability is clearly controlled by fractures.

CONCLUSIONS

Well logging proved useful and essential in the geothermal wells at the Cove Fort-Sulphurdale KGRA. Well logs contributed to better resolution of subsurface lithology, structure and fluid flow. However, the well logging could have been even more effective had higher-temperature production logging tools been available.

Better correlation between particular structures and flow might resolve the question of mixing of cooler fluids with geothermal fluids and the possibility of deeper, higher-temperature resources. High-temperature logging tools able to determine strike and dip of structures might permit the development of an accurate flow model for the KGRA.

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LIST OF ILLUSTRATIONS

- Figure 1 Map of Utah illustrating the location of the Cove Fort-Sulphurdale, KGRA, the adjacent geothermal resource areas, and the High Plateaus. The approximate outline of the Marysvale region is shown by the ruled pattern (modified from Callaghan, 1973).
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- Figure 3 Directional survey results for a) 14-29, b) 31-33 and c) 42-7.
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- Figure 8 Resistivity - neutron porosity crossplots for depth intervals (a) 610.2 m to 730.9 m and (b) 280.8 m to 1340.5 m in CFS 31-33 and depth interval (c) 1524.6 m to 1645.3 m in CFS 42-7. Data are 1.2 m averages.
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- Plate II Well log composite for CFS 31-33 (in pocket)
- Plate III Well log composite for CFS 42-7 (in pocket)

FIG. 1

EXPLANATION

	Alluvium (Quaternary)		Clinoptilolite-bearing ash-flow tuff (Miocene)
	Landslide deposits (Quaternary)		Older volcanic rocks and ash-flow tuffs (Oligocene to Miocene); includes lava flows, breccias and the Three Creeks Tuff Member of the Bullion Canyon Volcanics and the Tuff of Albinus Canyon
	Cinder cones of the Cove Fort basalt field (Pleistocene)		Price River Conglomerate (Cretaceous)
	Lava flows of the Cove Fort basalt field (Pleistocene)		Paleozoic and Mesozoic sedimentary rocks, undivided; includes metamorphosed equivalents at depth
	Ash-flow tuffs (Miocene); includes the Joe Lott Tuff of the Mount Belknap Volcanics and the Osiris Tuff		
	Dikes, stocks and flows of latitic composition (Miocene); includes quartz-monzonite dikes at depth		

FIG. 2

FIGURE 3a
DIRECTIONAL SURVEY
RESULTS FOR
UTAH STATE GEOTHERMAL
WELL 14-29; DATA FROM
SCHLUMBERGER LOG

FIGURE 3b

DIRECTIONAL SURVEY
RESULTS FOR
UTAH STATE GEOTHERMAL
WELL 31-33; DATA FROM
SCHLUMBERGER LOG

FIGURE 3c
DIRECTIONAL SURVEY
DATA FOR
UTAH STATE GEOTHERMAL
WELL 42-7; DATA FROM
SCHLUMBERGER LOG

Fig. 4

FIG. 5

FIG. 6

FIG. 6c

FIG. 7

FIG. 8

FIG. 8c

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PLATE I
LOG COMPOSITE OF
UTAH STATE GEOTHERMAL WELL
14-29

UNION OIL COMPANY WELL
 COVE FORT-SULPHURDALE, KGRA
 MILLARD COUNTY, UTAH
 MAY 1980

PLATE II
LOG COMPOSITE OF
UTAH STATE GEOTHERMAL WELL
31-33
UNION OIL COMPANY WELL
COVE FORT - SULPHURDALE, KGRA
MILLARD & BEAVER COUNTIES, UTAH
MAY 1980

PLATE III
LOG COMPOSITE OF
UTAH STATE GEOTHERMAL WELL
42-7

UNION OIL COMPANY WELL
COVE FORT - SULPHURDALE, KGRA
MILLARD & BEAVER COUNTIES, UTAH
JULY 1979