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INITIAL RESULTS FROM DRILLHOLES PLV-1 AND PLV-2 IN THE WESTERN MOAT OF THE LONG VALLEY CALDERA

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ABSTRACT

Core holes PLV-1 and PLV-2 are among the first intermediate depth geothermal exploration holes to be located in the western moat of the Long Valley caldera. PLV-1 was drilled through a sequence of moat rhyolite lava flows and tuffs and terminated in hydrothermally altered tuffs of the early rhyolite. PLV-2 was drilled through the moat basalt flows, a telescoped moat rhyolite sequence, and into the early rhyolite flows and tuffs.

The temperature profile from PLV-1 shows irregular and isothermal intervals created by downward moving meteoric water through hard fractured lavas to a depth of 1800 feet. Below 1800 feet the temperature gradient abruptly increases in soft impermeable tuffs to 36°F/100'. PLV-2 has an irregular temperature profile which can not be used for extrapolation purposes.

PLV-1 offers the first direct evidence that a geothermal reservoir is located to the west of Casa Diablo Hot Springs, however little can yet be said about the location, size, or depth of this reservoir.

INTRODUCTION

The Long Valley caldera in eastern California is the largest and most obvious exploration target for high-temperature geothermal resources in the Basin and Range province. The U. S. Geological Survey has intensively studied the Long Valley geothermal system as its type hot-water geothermal system (Jour. of Geophys. Res., 1976, Sorey et al., 1978). Exploratory drilling for high-temperature geothermal resources began at Casa Diablo in 1959 and has continued intermittently to the present. This drilling has followed a rather predictable pattern with shallow exploratory wells being drilled first in the immediate vicinity of the major thermal features. The next drilling phase consisted of deeper wells, still located near the obvious thermal features. This second phase, which included the Long Valley 66-29 well (Smith and Rex, 1977) and the Clay Pit and Mammoth No. 1 wells (Gambill, 1981) proved that the major, active thermal features in the central part of the caldera are not underlain by high-temperature reservoirs at economic depths. Consequently, the focus of recent exploration has shifted to the western part of the caldera where the only active thermal features are two small fumaroles high on Mammoth Mountain and recently discovered fumaroles a few miles northwest of Casa Diablo (Sorey, 1984). The timing of this evolution has been largely controlled by availability of U.S. Forest Service lands for geothermal leasing (Benoit and Butler, 1983).

In the summer and fall of 1982 Phillips Petroleum Company drilled intermediate depth holes PLV-1 and PLV-2 in the western moat of the caldera. This paper presents temperature, lithologic, and geochemical data from these two holes which now form the major public geothermal data base for the western part of the caldera.

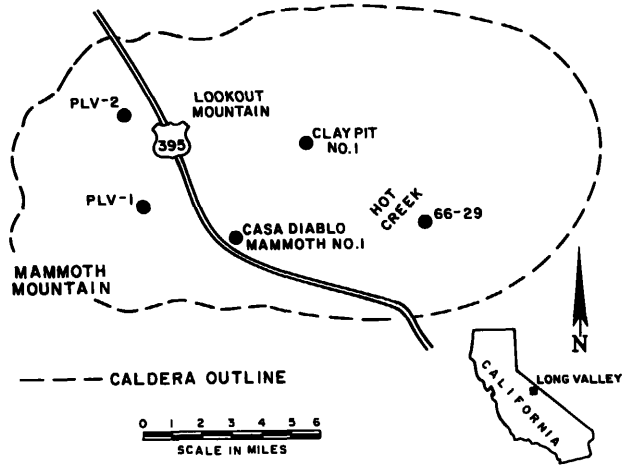

Figure 1. Index Map of Long Valley Caldera.

PLV-1

Drillhole PLV-1 is located about two miles west of Casa Diablo Hot Springs in NE/4 SE/4 Section 22, T 3 S, R 27 E (Fig. 1). There are two primary reasons for this location. First, this location was intended to evaluate the southern portion of the lands offered in the July, 1983 KGRA sale. Second, it was intended to help locate the source of the near-surface thermal aquifer which extends from west of Casa Diablo Hot Springs to Lake Crowley (Diment et al., 1980, Sorey, 1984, Blackwell, in press).

The bottomhole temperature of only 214 °F in the 5263 foot-deep Mammoth No. 1 well at Casa Diablo (Gambill, 1981) suggested that PLV-1 should be at least a mile or so away from Casa Diablo. Most drill hole locations are compromises between competing concerns and this one was no exception. To evaluate the most land possible within the KGRA it was believed necessary to have the hole at least a mile inside the KGRA boundary. This meant that PLV-1 would be located on topographically high land and there would be an elevation penalty in terms of increased depth to the point where a conductive temperature gradient could be expected. PLV-1 is located on top of one of the moat rhyolite lava flows (Bailey et al., 1976) at an elevation of 8480 feet, about 800 feet above the surrounding lowlands.

PLV-1 was drilled in three stages. A rotary rig was used to a depth of 458 feet. This stage was characterized by high costs due to continuous lost circulation. This resulted in numerous cement plugs being set. In the second stage a core rig was used to a depth of 1945 feet. Circulation was never achieved with the core rig but drilling proceeded quickly and relatively cheaply until soft, sticky clays were encountered at 1884 feet. After the extremely high temperature gradient below 1800 feet was measured the hole was again deepened to its total depth of 2345 feet when the drill string twisted off at 2014 feet. Fortunately the hole was completed with tubing inside the twisted-off drill rods to a depth of 2332 feet.

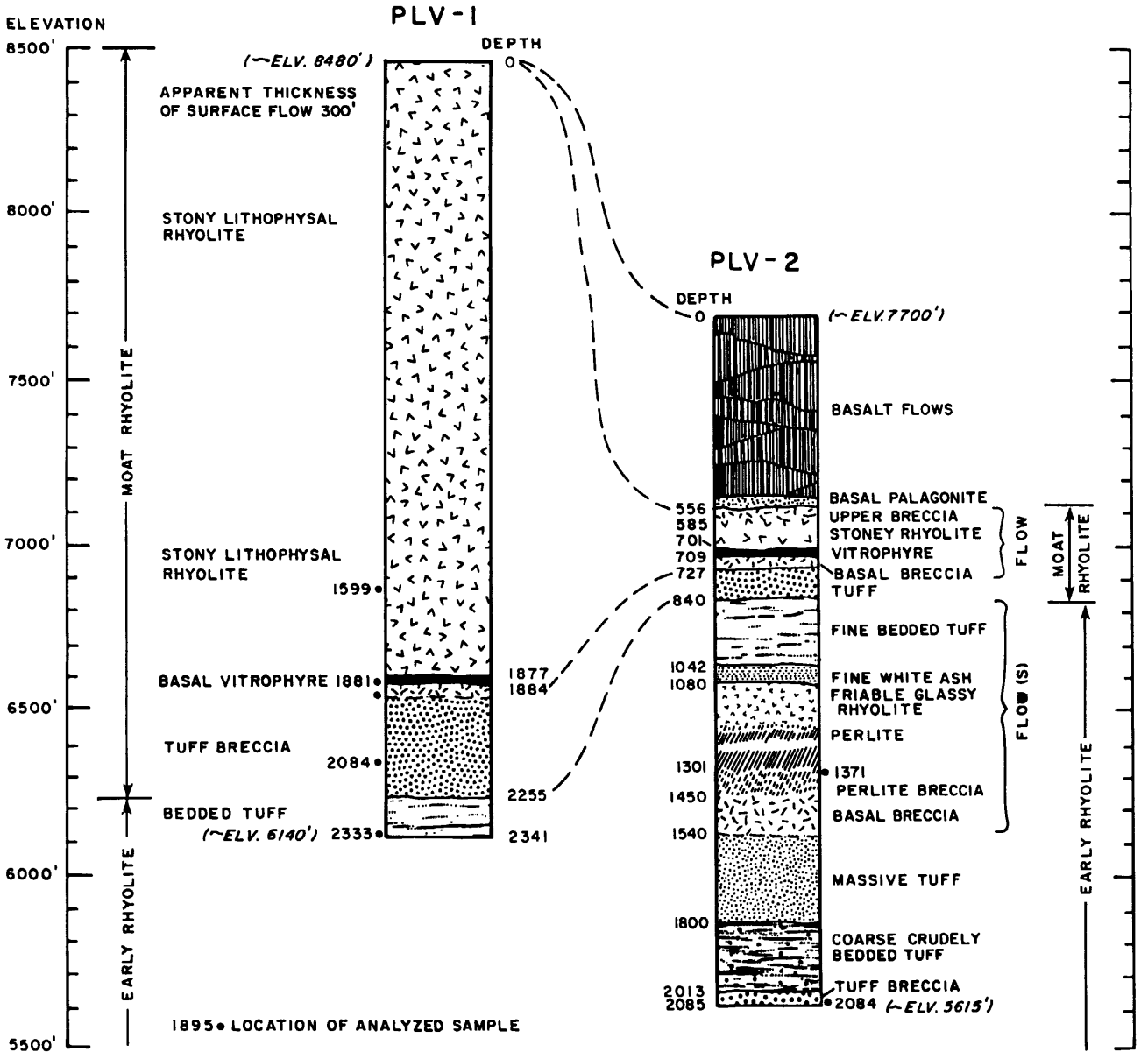

Figure 2. Lithologic Logs of PLV-1 and PLV-2 (prepared by Roy Bailey).

TABLE 1

CHEMICAL ANALYSIS, PHILLIPS GEOTHERMAL CORE HOLES, LONG VALLEY CALDERA

	<----------MOAT RHYOLITE---------->						<----------EARLY RHYOLITE---------->			
	M77-4 (USGS) w moat flow	PLV-1 1599 litho-physal rhyolite	PLV-1 1881 rhyolite vitro-phyre	PLV-1 1895 pumice breccia	PLV-1 2084 pumi-ceous tuff	PLV-1 2333 bedded ash	M72-79 (USGS) obsidian	PLV-2 137a grey perlite	PLV-2 1371b grey perlite	PLV-2 2084 bedded ash
SiO_2	70.2	73.09	71.53	76.03	76.83	75.73	74.60	72.97	73.10	71.39
TiO_2	.27	.28	.28	.28	.21	.21	.14	.14	.14	.18
Al_2O_3	13.5	13.86	13.77	15.20	13.90	14.80	13.52	13.38	13.41	12.90
Fe_2O_3	.93	2.00	2.25	1.51	1.55	1.62	.27	1.10	1.29	1.28
FeO	1.2	-	-	-	-	-	.99	-	-	-
MnO	.09	.06	.06	.02	.02	.03	.04	.02	.02	.03
MgO	.40	.33	.34	.20	.26	.20	.12	(<.06)	(<.06)	.15
CaO	1.3	1.08	1.10	.37	.29	.03	.77	.58	.58	.78
Na_2O	4.1	3.92	3.85	(<.25)	(<.25)	(<.25)	3.84	2.13	2.14	2.15
K_2O	4.7	4.40	4.33	2.93	4.22	4.84	5.14	5.12	5.09	4.73
P_2O_5	.07	.07	.07	.03	.02	.03	.02	.02	.02	.02
H^2O^+/LOI	2.2	.23	2.24	4.03	2.98	2.46	.17	4.07	4.07	6.16
H_2O-	.62	(.38)*	(.10)	(2.88)	(2.42)	(.41)	.00	(.58)	(.58)	(1.15)
S	-	(<.05)	(<.05)	(.39)	(.42)	(.38)	-	(<.05)	-	(<.05)
TOTAL	99.6	99.32	99.82	100.60	100.28	99.95	99.62	99.53	99.86	99.77

Notes: H_2O^+: Total H_2O by Penfield method less H_2O^-. (USGS analyses only)
LOI: (loss on ignition) does not include H_2O^-. (Phillips analyses only)
H_2O^-: USGS analyses: loss on heating 1 hr. at 105°C.
Phillips analyses: loss on heating overnight at 105°C.
*Numbers in parentheses not included in totals.

RECALCULATED VOLATILE-FREE

SiO_2	72.6	73.76	73.30	78.73	78.96	77.68	75.01	76.44	76.31	76.26
TiO_2	.28	.28	.29	.29	.22	.22	.14	.14	.14	.19
Al_2O_3	14.0	13.99	14.11	15.74	14.29	15.18	13.59	14.02	14.00	13.78
Fe_2O_3	.96	2.02	2.31	1.56	1.59	1.66	.27	1.15	1.35	1.37
FeO	1.2	-	-	-	-	-	1.00	-	-	-
MnO	.09	.06	.06	.02	.02	.03	.04	.02	.02	.03
MgO	.41	.33	.35	.21	.27	.21	.12	<.06	<.06	.16
CaO	1.3	1.09	1.13	.38	.30	.03	.77	.61	.61	.83
Na_2O	4.2	3.96	3.95	<.25	<.25	<.25	3.86	2.23	2.23	2.30
K_2O	4.9	4.44	4.44	3.03	4.34	4.96	5.17	5.36	5.31	5.05
P_2O_5	.07	.07	.07	.03	.02	.03	.02	.02	.02	.02
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Cl	-	135	393	<100	369	583	-	269		381
V	10	<20	<20	48	32	29	<15	<20		<20
Ni	<10	<20	<20	<20	<20	<20	<10	<20		<20
Cu	1	<20	<20	<20	<20	<20	3	<20		<20
Pb	<20	<50	<50	<50	<50	<50	<20	<50		52
Th	13.7	<50	<50	<50	<50	<50	15.4	<50		<50
Rb	127	148	128	120	178	180	140	155		154
Sr	100	174	162	103	<50	86	90	78		112
Zr	254	225	258	146	165	169	191	182		227
Ba	832	849	962	621	1432	925	1120	1022		1232

PLV-1 encountered 1884 feet of competent, permeable moat rhyolite lava flows (Fig. 2). These lava flows are hard, stony textured rocks with phenocrysts of quartz, sanidine, plagioclase, hornblende, and biotite as previously described by Bailey et al. (1976). The bottom six feet of this flow sequence is a basal vitrophyre.

Chemical analyses of the moat rhyolite by Phillips Petroleum Company at depths of 1599 and 1881 feet are very similar to an unpublished U. S. Geological Survey analysis of moat rhyolite flow rock from the surface (Table 1). Below the hard moat rhyolite lavas three different soft units have been recognized. The uppermost is a basal pumice breccia related to the overlying lava flows. Next there is a pumiceous tuff, also part of the moat rhyolite sequence, which extends down to a depth of 2255 feet. Below 2255 feet a white pyritized homogeneous bedded ash is present. This ash lacks

primary phenocrysts and therefore is a unit of the early rhyolite sequence (Bailey et al., 1976). The chemistry of these three soft units (Table 1) does not accurately represent the original composition due to extensive later hydrothermal alteration. There has obviously been leaching of sodium and pyritization.

A temperature profile of PLV-1 obtained 5 days after recompletion on Oct. 26, 1982 is shown on Fig. 3. Normally 5 days is not long enough for the hole to rebound to static thermal conditions. However, comparison with the Oct. 1, 1982 temperature profile obtained 24 days after the initial completion at 1945 feet indicates the Oct. 26 profile is close to static. These two surveys were obtained with different thermister type instruments which may in part explain the apparent temperature differences. The two instruments have not been calibrated against each other.

The stratigraphy, with its high permeability contrast, strongly controls the shape of this temperature profile. To a depth of 500 feet the profile is basically isothermal. Two temperature maxima at depths of 220 and 380 feet are apparently the result of cooling cement in major lost circulation zones. Between 500 and 1000 feet the temperature gradient shows a smooth progressive increase. At 1100 feet the profile becomes isothermal and stays so to a depth of 1800 feet. During electrical logging, standing water was encountered in PLV-1 at a depth of 991 feet. The significance of the 991 foot depth is not known because the water level was only measured once, immediately after drilling operations. This is close to a minor inflection point in the profile at 1000 feet but 109 feet above the top of the isothermal section. At 1800 feet the temperature gradient abruptly increases to 36°F/100' and maintains this gradient to 2332 feet where a bottomhole temperature of 255°F is present.

The main inflection point of the PLV-1 temperature profile at 1800 feet is quite close to the bottom of the competent moat rhyolite lavas at 1884 feet. Above 1884 feet the moat rhyolite has many large high-angle fractures visible in the core and was characterized by severe lost circulation during drilling. Below 1884 feet the soft rocks show no visible permeability in the core. The high temperature gradient interval extends 84 feet up into the fractured competent lavas. It is not known if this is a local anomalous feature or if it occurs over a large area at the base of the moat rhyolite lavas but vertical water movement can not be occurring in this 84 feet.

From a geothermal exploration viewpoint hole PLV-1 is important in that it provides the first direct evidence of high temperature in the western moat of the Long Valley caldera.

PLV-2

Drillhole PLV-2 is located in the west moat of the caldera in NW/4 SE/4 Section 3 T3S, R27E. The primary purpose of this location was to fill in a large gap in Phillips Petroleum Company's data base. PLV-2 was drilled to a total depth of 2100 feet in a single stage of core drilling.

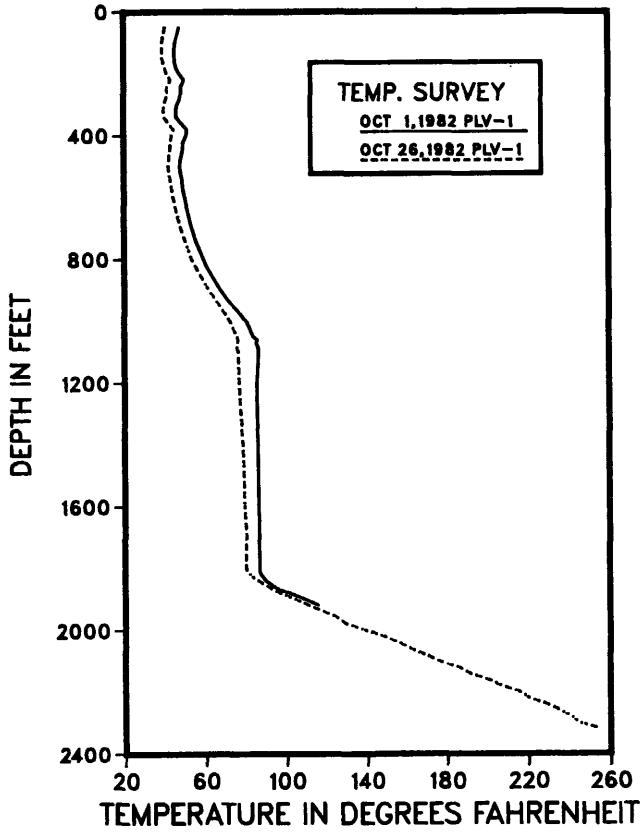

Figure 3. Temperature Profiles of PLV-1.

PLV-2 is located on moat basalt flows (Bailey et al., 1976) and penetrated a sequence of basalt flows with thin interbedded units of soil, ash, cinders, and palagonitic tuff to a depth of 556 feet (Fig. 2). Below 556 feet the lithologies are entirely rhyolitic in composition. Between 556 and 840 feet a telescoped sequence of stony rhyolite, vitrophere, basal breccia, and tuff comparable to the moat rhyolite sequence in PLV-1 is present. No chemical data were obtained from the moat rhyolite sequence in PLV-2. Below 840 feet flows and tuffs of the early rhyolites are present. Flows, in part perlitized, are above a depth of 1540 feet and tuffs are below 1540 feet.

Chemical analyses from an early rhyolite perlitic breccia and a tuff at the bottom of the hole are presented in Table 1. This chemistry is quite similar to that of an early rhyolite obsidian flow from Lookout Mountain. The rocks in PLV-2 show little evidence of hydrothermal alteration which is in marked contrast to the rocks near the bottom of PLV-1.

Two non-equilibrium temperature profiles and one partial equilibrium temperature profile are shown on Fig. 4. PLV-2 was completed on Oct. 3, 1982 and logged for the first time on the same day. This initial profile is somewhat irregular but does bear a good resemblance to the equilibrium

profile as shown by the close correlation with the U. S. Geological Survey data obtained one year after completion (M. Sorey, pers. comm.).

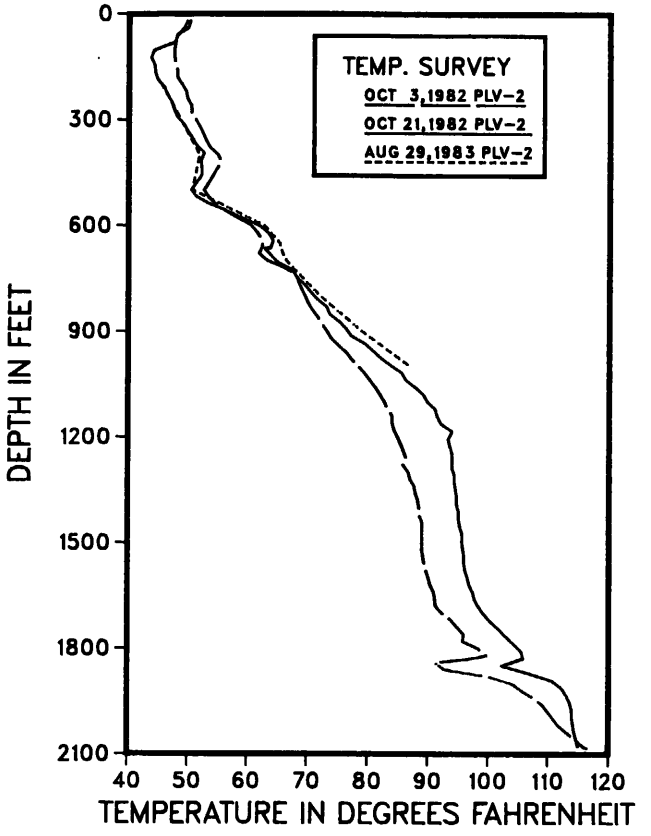

Figure 4. Temperature Profiles of PLV-2.

The temperature reversals on the Oct. 3 and 26 logs at depths of 680 and 1880 or 1900 feet appear to be caused by the drilling disturbance. However, the temperature reversal at 500 feet appears to be a static feature as it is present a year after completion. Below a depth of 1000 feet equilibrium data are not available but the profile is expected to approximate the Oct. 21 curve. The equilibrium temperature is probably near-isothermal between about 1200 and 1600 feet with a temperature near 95°F. Between 1600 and 1900 feet there is a positive temperature gradient but below this depth isothermal or near-isothermal conditions with a temperature of 115°F again appear to be present.

The temperature profiles and lithologies do not correlate very well in PLV-2. For instance, it was expected that the profile through the basalts and more competent upper part of the moat rhyolite would be strongly influenced by downward moving meteoric water and have little or no temperature gradient. In the tuff units in the bottom of the hole it was expected that a conductive gradient would be present. There were even good returns of fluid during drilling of this interval but the temperature profile proves there is convective transfer of heat in this interval.

PLV-2 is a disappointing hole in that it was not drilled deep enough to provide temperature data which can be extrapolated. The thermal regime below the bottom of this hole remains speculative.

DISCUSSION

Drillhole PLV-1 has demonstrated that the Long Valley geothermal system extends into the western third of the caldera. This in part confirms the conclusion of Lachenbruch et al. (1976) that the western part of the caldera serves as the heat source for the thermal springs at Hot Creek and Casa Diablo. PLV-1 also has demonstrated that core drilling is a more effective technique than conventional rotary drilling in the hard, highly permeable, near-surface rocks in the western part of the caldera. These highly permeable rocks permit rapid downward movement of cold meteoric waters. Therefore, all future temperature-gradient holes should, at a minimum, be drilled into the softer, less permeable underlying tuffs. However, the results from PLV-2 show that even this does not guarantee temperature data which can be extrapolated.

The thermal regime beneath PLV-1 remains unknown. All too often in geothermal exploration extremely high temperature gradients have reversed at less than desirable temperatures with deeper drilling. It is not possible to predict if this highly promising temperature gradient will reverse. If the gradient continues, geochemically predicted reservoir temperatures of 426 to 540°F would be encountered in the Bishop tuff, or even possibly

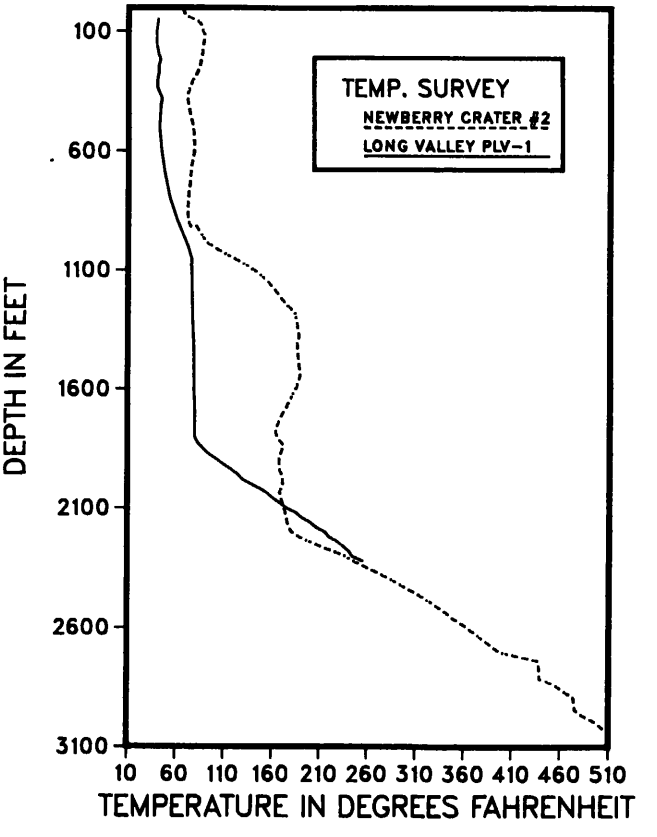

Figure 5. Temperature Profiles of PLV-1 and Newberry #2.

in the early rhyolite. If the temperature gradient reverses, the reservoir will be at greater depths, possibly as deep as the granitic basement. With this limited data little can be concluded about the location or areal extent of the reservoir.

To conclude on an optimistic note, there is a precedent for believing the high temperature gradient in PLV-1 will continue. Figure 5 shows both PLV-1 and the Newberry 2, Oregon temperature profiles. Both holes are located in very similar geologic and hydrologic regimes and the high temperature gradient in Newberry 2 continues to a temperature of 509°F (Sammel, 1983).

ACKNOWLEDGEMENTS

Thanks are due to Phillips Petroleum Company for permission to publish this paper and for typing and drafting assistance in its preparation. Also, a great deal of credit is due Roy Bailey for the use of his preliminary lithologic logs of PLV-1 and PLV-2 and for the two previously unpublished chemical analyses on Table 1. Roy also provided the recalculated values on Table 1.

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