Geothermal Resources Council, TRANSACTIONS Vol. 6, October 1982

AN INTERPRETATION OF PRECISION TEMPERATURE LOGS IN A DEEP GEOTHERMAL WELL NEAR DESERT PEAK, CHURCHILL COUNTY, NEVADA

Thomas C. Urban and William H. Diment

U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025

ABSTRACT

Three precision (~ 0.001°C), continuous (0.6 m sensing interval) temperature logs (7/25/79, 7/27/79, and 10/19/79) were obtained in Phillips Petroleum Company's deep (2931 m) geothermal well B23-1 (39°45.6'N, 118°55.6'W, elevation 1393 m) a few months after completion of drilling (5/24/79). The measurements were made in a small diameter (6.2 cm I.D.) tubing capped at the bottom and extending from the surface to near total depth in the hole which ranged in diameter down to 20 cm. A 34 cm (O.D.) casing was cemented into place in the upper 901 m of the hole. The remainder of the hole was open, allowing the exchange of fluids among the many permeable zones encountered during drilling. Analysis of the temperature logs suggest the following: (1) The linearity of the temperature plot in the interval 200-900 m (after allowing for decay of the drilling disturbance) suggests the existence of a hydrothermal system of considerable antiquity (> 10^3 years). The high gradient (~180°C/Km) and high heat flow (> 5 microcal/cm^2 · sec) in this interval require that heat be transported convectively to the base of this interval. (2) The interval between about 900 and 1300 m exhibits anomalous warming since drilling. Although some of this warming represents decay of the thermal disturbance due to invasion of cool drilling fluids, a part of it may represent an invasion of hot water into the hole which then descends along the hole and exits into many permeable zones at greater depth. This could, of course, obscure the true nature of the thermal regime of the rocks surrounding the lower part of the hole.

INTRODUCTION

A considerable effort has been made in the exploration for geothermal resources in the area in western Nevada approximately 80 km east of Reno. Located in the Hot Springs Mountains, the Desert Peak geothermal system encompasses an area of roughly 250 sq. km. It was originally discovered by Phillips Petroleum Company while drilling temperature-gradient holes near Brady's Hot Springs, about 15 km to the northwest. Subsequent drilling in the Desert Peak area established it as a separate system. Evaluation of this thermal anomaly was partially funded by the Department of Energy and much of the information gathered at this site has been, or is being, released (e.g., Benoit, 1978; Benoit et al., 1980; Sethi and Fertl, 1979).

Although there is a considerable quantity of data that could be examined, our attention is restricted to the interpretation of three precision temperature logs that we obtained several months after drilling in the deepest of the exploratory wells (Phillips Petroleum Company B23-1). The results are of interest because they show that the fine structure of the temperature variation with depth can be reliably and repeatably obtained in a deep, high-temperature (~205°C) environment, and that this fine structure can yield useful information about conditions in and immediately surrounding the hole.

EXPERIMENTAL PROCEDURES AND UNCERTAINTIES

The logging system consists of a thermistor lowered at the end of a steel-armored, 4-conductor, teflon-insulated cable. The resistance of the thermistor is digitally recorded at the surface. When malfunctions occurred they were usually the result of leakage at the cable head which connects the probe containing the thermistor to the cable. In logging B23-1, the filler between the leads and the armor charred, thus making it difficult to rehead the cable. Our problem is reminiscent of that encountered by Mathews et al. (1981) in a more extreme environment. Uncertainties due to convection in the hole and other noise are discussed elsewhere (Diment and Urban, 1982).

ANALYSIS OF TEMPERATURE LOGS

The general characteristics of the temperature and temperature gradient profiles are illustrated in Figure 1. These profiles can be divided roughly into three parts: (1) a near-surface zone (0-900 m) of high but rather uniform gradient, which shall be referred to as the "conductive cap"; (2) a zone of high temperatures and variable gradients, here termed the "injection zone" (900-1300 m); and (3) a zone of high temperature, but of low or even negative gradients, here termed the "reservoir." In discussing these zones, we rely heavily on the summaries of Sethi and Fertl (1979) and Benoit et al. (1980).

The "conductive cap" appears conductive in the sense that the temperature profiles are rather

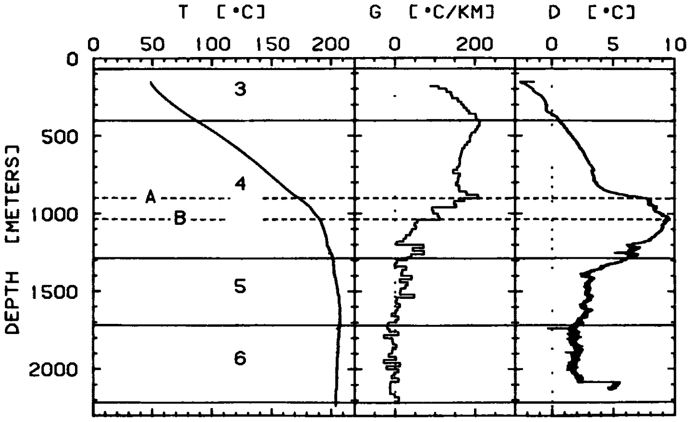

Figure 1. Temperature log (T) recorded at 0.6 m intervals in Desert Peak well B 23-1 on 10/19/79. Temperature gradients (G) were determined over 20 m intervals. Temperature differences (D) represent T (10/19/79) minus T (7/25/79). No attempt has been made to remove spikes due to electrical noise. Solid horizontal lines separate major geologic units which are designated by numbers (Table 1). Level A is the base of the casing (901 m) which is close to a zone of lost circulation (928 m). Level B (1036 m) is a major zone of porous rock with low formation pressure (Sethi and Fertl, 1979, p. 11). All depths are relative to ground level which is 8 m below the Kelley bushing.

linear (Fig. 1) and would be more so if a correction for the drilling disturbance were applied. Note that the cross over point in the cooling/heating history (Figs. 1 and 3) is near 350 m. Also note that this is the only interval in the hole in which a cemented casing (0-901 m) prevents exchange of fluids among aquifers. Silicified zones in this interval attest to past geothermal activity. Zones of hot-water flow at shallow depths nearby indicate present hydrothermal activity (Benoit, 1978). Judging from the linearity of the profile in B23-1, the temperature at the base of the cap has been rather uniform for some time. Given the calculations that we made in estimating the age of The Geysers Steam field (Urban et al., 1976, Fig. 4), the temperature of the base of the cap has maintained near its present level for at least 10^3 years and possibly much longer. The heat flux through the cap is so large (~180°C/km x ~3 + millical/cm · sec. °C = ~5 + micro cal/cm^2 · sec) and the gradient below it so low, that heat must be delivered to the base of the cap by the flow of hot water.

The behavior of the "injection zone" is complex. Given the considerable rise in temperature in the injection zone between 7/25/79 and 10/19/79 (Figs. 1 and 3), it is probable that the temperatures will increase further. How much more they will increase is difficult to estimate, because the effect of the invasion of drilling fluid into permeable formations can be large and long-lasting (e.g., Nathenson et al., 1980). Moreover, we are not sure that our temperature logs made in the tubing reflect the true range of temperatures in the outer regions of the hole. Temperature logs in some other injection zones, as sensed both in small diameter holes (e.g., Diment et al., 1980) and in large diameter holes (e.g., Diment, 1980, Fig. 2.3), exhibit large temperature variations (several degrees) over short intervals of depth (several meters).

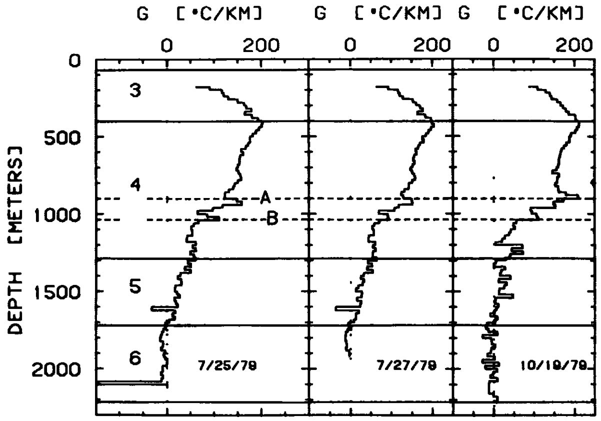

Figure 2. Temperature gradient logs (20 m interval) obtained in Desert Peak well B23-1 on the dates indicated. See Figure 1 for explanation of symbols.

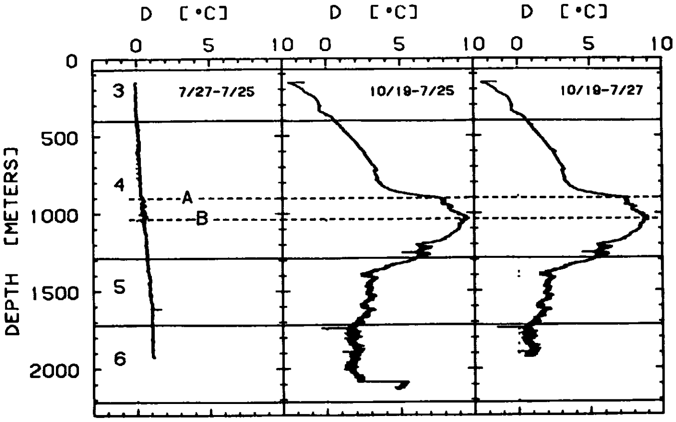

Figure 3. Temperature differences between logs obtained in Desert Peak well B23-1 on the dates indicated. See Figure 1 for explanation of symbols.

We suggest that hot water is cascading down the hole from various permeable intervals in the injection zone and that this has lead to the decreasing gradients with time in the region immediately below the injection zone (Fig. 2). It also appears that the maximum temperature in the upper part of the hole (<2500 m) may occur ultimately at level B, with an "equilibrium" temperature profile being nearly linear from 200 m to level B (1034 m) and thence declining.

The "reservoir" extends from near the base of unit 4 (1288 m) nearly to the bottom of the hole. The zone is marked by relatively high temperatures and low thermal gradients. The temperatures and the temperature gradients (Fig. 2) change with time in a manner that cannot be explained in terms of the conductive thermal-decay of the drilling disturbance. They are, however, explainable in terms of a hot fluid flowing downward through the hole and flowing out at various levels of low pressure and high permeability; many such intervals were documented in the process of drilling (Benoit et al., 1980).

The temperature profile may be rather like that observed by Blackwell and Morgan (1976) in a deep geothermal well (MGE No. 1) near Marysville, Montana. The form of the temperature-depth curve is similar to that in B23-1, although the amplitude is not. Moreover, the changes of the temperature curves with time after drilling are similar (Blackwell and Morgan, 1976, Fig. 5). Flow velocity logs obtained in MGE No. 1 indicate a large downward flow of water from fractures from 900 to 1100 m. The "reservoirs" in both holes are largely in granitic rocks, and both holes, mostly uncased, are sub-hydrostatic at the well-head.

The true rock temperatures in the "reservoir" are not known. They are less than those indicated by the temperature logs at least to a depth of about 2700 m where the measured gradient turns mildly positive (14°C/km, Benoit et al., 1980, p. 16). The question is: How much less?

An alternative speculation is that the "reservoir" is a weakly developed vapor-dominated system (e.g., White et al., 1971) whose identity has been masked by the drilling process, that involved drilling with mud to 927 m, with water to 2800 m, and with aerated water to the bottom (Benoit et al., 1980). In the well-known vapor-dominated system at The Geysers, the temperature and pressure in the main steam reservoir (> 1500 m) are 240°C and 40 bars (near the maximum enthalpy of steam).

CONCLUSIONS

With a little bit of luck and considerable attention to detail, precision temperature logs can be obtained in high temperature environments (~200°C) with modern, largely off-the-shelf components. Precision temperature logs, especially when repeated so that temperature difference logs can be constructed, may provide useful information about the motion of fluids within and surrounding a hole.

Table 1. Major geologic units encountered in well B 23-1 (abstracted from Phillips Petroleum Co., 1979, Fig. 9; and Benoit et al., 1980, Fig. 5)

INTERVAL	(M)	GEOLOGIC UNIT
1	0-12	Sand, gravel and boulders
2	12-69	Lacustrine sediments of Pliocene Trukee Formation occasional silicification.
3	69-404	Basalt, basaltic andesite, and andesite of Chloropagus Formation.
4	404-1288	Andesitic to rhyolitic ash-flow tuffs - Miocene. Basal 20 m contains gravel, talus(?), soil(?), and both phyllite and volcanic chips.
5	1288-1719	Metamorphosed Mesozoic sedimentary rocks, predominately phyllite.
6	1719-2216	Roughly equal amounts of granite and chlorite schist and chlorite schist and hornfels.
7	2216-2939	Mostly granite to T.D. (2939 m).

The hydrothermal system near Desert Peak, as revealed by temperature logs and other information obtained from well B23-1, appears similar to many others in the sense that: (1) the temperature field is dominated by the sub-horizontal flow of anomalously hot water along a confined aquifer of limited thickness that owes its source of hot water to an adjacent conduit which taps a deeper high-temperature reservoir and (2) the probable movement of water down the hole obscures the true nature of the thermal regime below the high temperature aquifer that provides the descending hot water.

ACKNOWLEDGEMENTS

We thank R. T. Forest of the Phillips Petroleum Company for arranging access and support at the site and for sharing his knowledge of the history of the project. The manuscript was read and improved by W. B. Joyner and A. H. Lachenbruch.

REFERENCES

Benoit, W. R., 1978, The use of shallow and deep temperature gradients in geothermal exploration in northwestern Nevada using the Desert Peak thermal anomaly as a model: Geothermal Resources Council, Transactions, v. 2, p. 45-56.

Benoit, W. R., Sethi, D. K., Fertl, W. H., and Mathews, M., 1980, Geothermal well log analysis at Desert Peak, Nevada: Society of Professional Well Log Analysts 21st Annual Symposium, July 8-11, 1980, Paper AA, 41 p.

Blackwell, D. D., and Morgan, P., 1976, Geological and geophysical exploration of the Marysville geothermal area, Montana, USA: Second United Nations Symposium on the Development and Use of Geothermal Resources, Washington, D.C., U.S. Government Printing Office, p. 895-902.

Diment, W. H., 1980, Geology and geophysics of geothermal areas, in Kestin, J., ed., A source book on the production of electricity from geothermal energy: Washington, D.C., U.S. Government Printing Office, p. 7-103.

Diment, W. H., Urban, T. C., and Nathenson, M., 1980, Notes on the shallow thermal regime of the Long Valley Caldera, Mono County, California: Geothermal Resources Council, Transactions, v. 4, p. 37-40.

Diment, W. H., and Urban, T. C., 1982, Temperature changes with time in the slotted interval of a deep, shut-in geothermal well near thermal equilibrium - East Mesa well 31-1, Imperial County, California, 1977-1982: Geothermal Resources Council, Transactions, v. 6.

Mathews, M., Pettit, R. A., and Miler, D. J., 1981, High temperature logging for basic development of HDR reservoirs: Geothermal Resources Council, Transactions, v. 5, p. 299-302.

Nathenson, M., Urban, T. C., Diment, W. H., and Nehring, N. L., 1980, Temperatures, heat flow, and water chemistry from drill holes in the Raft River geothermal system, Cassia County, Idaho: U. S. Geological Survey Open-File Report 80-2001, p. 29.

Phillips Petroleum Company, 1979, Geothermal resource assessment case study, northern Basin and Range Province, final report for the period 1 October 1978-30 September 1979, U.S. Department of Energy Report DOE/ET/27099-1: Springfield, Virginia, U.S. Department of Commerce, National Technical Information Service, 114 p.

Sethi, D. K., and Fertl, W. H., 1979, Geophysical well logging operations and log analysis in geothermal well Desert Peak No. B-23-1: Dresser Atlas Report for Los Alamos Scientific Laboratory, LA-8254-MS, 69 p.

Urban, T. C., Diment, W. H., Jamieson, I. M., and Sass, J. H., 1976, Heat flow at the Geysers, California, in Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources: Washington, D. C., U. S. Government Printing Office, v. 2, p. 1241-1245.

White, D. E., Muffler, L. J. P., and Truesdell, A. H., 1971, Vapor-dominated hydrothermal systems compared with hot-water systems: Economic Geology, v. 66, p. 75-97.