DRILLING, COMPLETION AND TESTING OF GEOTHERMAL WELLS CD-1 AND CD-2, CALIENTE, NEVADA

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ABSTRACT

Two geothermal test wells (CD-1, CD-2) were drilled in January, 1983, in Antelope Canyon to assess the potential for resource utilization by the City of Caliente's proposed space heating district. Both holes drilled into bedrock at 220 feet, encountered hot water in the upper part of the hole (40 to 100 ft.) and cooler water below (100 to 210 ft.). Lithologic logs reveal that a clay layer, in the vicinity of the temperature reversal, represents an aquitard that limits fluid mixing.

A series of pump tests, completed on CD-1 in February, 1983, indicate that the transmissivity of the thermal aquifer is very high. A pumping rate of 255 gallons per minute at 80°C (178°F) may be considered a minimum. Drawdowns of 3 to 6 feet recovered instantly after pumping was stopped. Pumping of this well did not affect the water levels of two nearby observation wells. Significant temperature increases were recorded in both observation wells during the last few days of the tests.

Chemical analyses of five water samples collected during the course of CD-1 pump tests indicate little or no change in composition over the period of testing, and demonstrate a high degree of correlation with nearby thermal fluids. Chemical geothermometers suggest that the maximum temperatures from this resource range from 120 to 140° C. The highest temperature measured in this resource is 96°C.

INTRODUCTION

In November, 1979, the Nevada Geothermal Resource Assessment Team was asked to perform a preliminary assessment of the geothermal resources of Caliente, Nevada (Trexler and others, 1980). This program was funded by the U.S. Department of Energy (contract no. DE-AC08-79NV10039) and included collection of existing data, geologic reconnaissance, temperature measurements in springs and wells, two meter-depth temperature probe surveys, and chemical analyses of water and soil samples. The report recommended that two test wells be drilled to a depth of 500 feet to confirm the extent of the resource; the drill sites were selected on the basis of geophysical and geologic observations and are shown in Figure 1 (Test Wells #1 and #2).

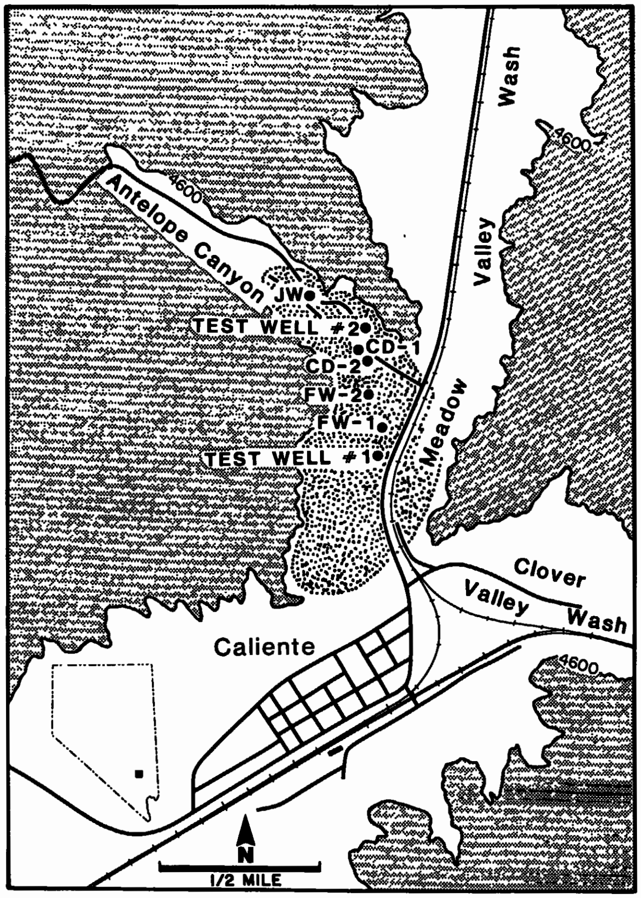

Figure 1: Location map showing distribution of thermal waters (stippled pattern), thermal wells and recommended test well sites.

In addition to the Resource Assessment Program, the Nevada Department of Energy requested technical assistance from the Geo-Heat Utilization Center, Oregon Institute of Technology (OIT). The final report, District Heating System, City of Caliente, Nevada (1980), included an engineering and economic study of the feasibility of installing a geothermal district heating system. The report concluded that the proposed district heating system was economically feasible. It assumed a geothermal resource capable of delivering 71°C (160°F) fluids at a peak load of 850 GPM, from a relatively shallow depth near the city boundaries.

The City of Caliente subsequently applied for and received additional federal funds to drill the two holes recommended by the Resource Assessment Team.

This paper describes the drilling, completion and testing of two geothermal wells in Antelope Canyon, located just north of Caliente. Funding for this program was supplied by the U.S. Department of Energy Appropriate Energy Technology Program, grant number DE-FG03-81SF11624.

GEOLOGY GEOTHERMAL RESOURCES

Caliente is located in Lincoln County, Nevada, at the confluence of Meadow Valley Wash and Clover Valley Wash. The City is situated in a steep-walled canyon that consists principally of Cretaceous-Tertiary rhyolite. The canyon floor is composed of Quaternary alluvium consisting of sand, silt, clay, gravels and cobbles.

Antelope Canyon is a very narrow, northwest-trending ravine that transects several major lithologic units. In the vicinity of drill sites CD-1 and CD-2 (fig. 1), the canyon walls consist of late Cretaceous to early Tertiary undifferentiated perlitic rhyolite. Immediately west of the drill sites, a middle Cambrian undifferentiated hydrothermally altered limestone-dolomite is in thrust fault contact with the lower Cambrian Prospect Mountain Quartzite. The plane of the thrust fault strikes north, across the axis of the canyon, and has a near-vertical dip. This vertically-dipping limestone may represent the near-surface structural control for rising thermal fluids. Temperature distribution of fluids suggests lateral flow to the southeast through the unconsolidated alluvium that overlies the rhyolite bedrock.

Prior to initiation of this drilling program, the highest geothermal fluid temperature in Caliente was 67°C (153°F). This temperature was recorded in well FW-1 (fig. 1) at approximately 60 feet. Thermal fluids are distributed throughout the north part of the City. Temperatures range from 24°C to 67°C. A temperature-depth profile completed on well JW (fig. 1) before drilling began recorded a maximum temperature of 80°C (176°F) at a depth of 80 feet.

Geothermal fluid utilization in Caliente consists largely of space heating a trailer park and hospital. In addition, thermal fluids are used directly for a laundry facility, a geothermal spa, and a car wash.

DRILLING SPECIFICATIONS & MONITORING TECHNIQUES

Drill site selection was ultimately based on the availability of a 1.3 acre parcel of land adjacent to test well #2 drill site recommended by Trexler and others (1980). All drilling was completed with a Portadrill 524 rotary mud rig. Drill chip samples were collected at 10 foot intervals and return mud temperatures were monitored continuously.

Drilling began in January, 1983. Hole CD-1 was drilled to a total depth of 220 feet. Rhyolite bedrock was encountered at 210 feet. A temperature profile indicated a temperature reversal at approximately 100 feet (fig. 2). A decision was then made to complete hole CD-1 as a production well for test pumping and chemical analyses of the thermal fluids. The well was reamed out with a 12 inch diameter bit to a depth of 100 feet and cased with 8 5/8 inch blank casing from the surface to a depth of 60 feet. The production zone (the bottom 40 ft.) was cased with 8 5/8 inch stainless steel screen (3/16 in.). The hole was gravel packed around the screen and a phosphate solution was swabbed through the gravel. The well was sealed with cement from the surface to a depth of 50 feet.

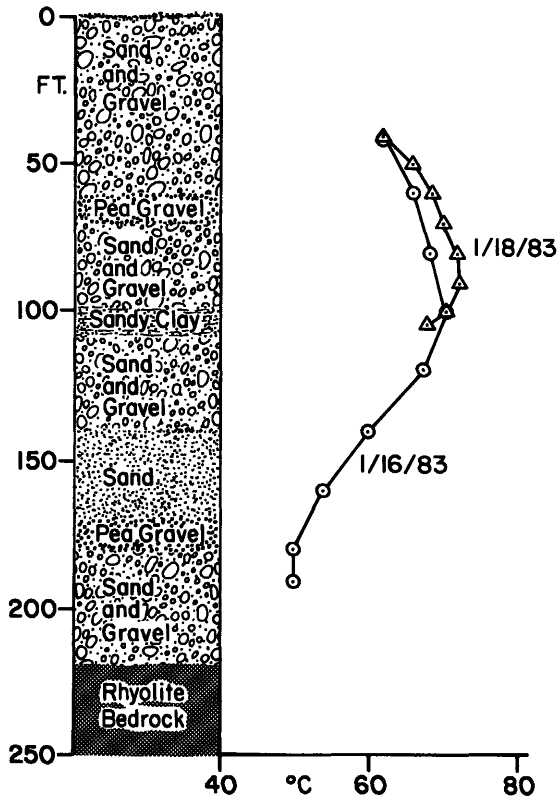

Figure 2: Lithologic log and temperature depth profiles of well CD-1.

Well CD-2 was drilled as an observation well to a depth of 220 feet. This well was cased with 2 inch diameter steel to 220 feet. The bottom 80 feet of casing had torch-cut perforations and was gravel packed. The top 20 feet was cemented.

ANALYSIS OF DRILL HOLE DATA, CD-1, CD-2

Combined analysis of temperature-depth profiles and lithologic logs from drill holes CD-1 and CD-2, in conjunction with temperature gradients measured in nearby wells, show that geothermal fluids in Antelope Canyon are widespread, but are restricted to a zone located between 40 and 100 feet below the surface. Thermal waters in Antelope Canyon are underlain by cooler waters, which are in turn underlain by rhyolite bedrock. A maximum temperature of 81°C (177°F) was measured in J. Wilkens' well (JW, fig. 1).

The aquifer for both thermal and non-thermal waters is young alluvium and consists of varying proportions of sand and gravel with clay-rich fractions and occasional layers of larger cobbles and boulders. The material is all locally derived and consists largely of Prospect Mountain quartzite and Cretaceous-Tertiary rhyolites. Minor basalt, shale, and carbonate are also present.

Temperature reversals in both drill holes clearly delineate the lower boundary of the thermal waters. Clays found in drill cuttings from both holes are coincident with the temperature reversal and likely form a semi-permeable barrier (aquitard) between the two waters (fig. 2). The probable source of the cold waters is Meadow Valley Wash, but the Antelope Canyon drainage may also contribute. Mixing of thermal and non-thermal waters is probably occurring naturally throughout Antelope Canyon. The source of the thermal waters is not known for certain. A likely candidate is the hydrothermally altered carbonate, which has been thrust over the Prospect Mountain quartzite. The carbonate dips at approximately 90° and strikes N30°E across the canyon, approximately 500 feet west of CD-1. The source of the heat is probably the result of deep circulation along faults. Pliocene basalts mapped west of Caliente in Dry Lake Valley (Tschanz and Pampeyan, 1970) should not be ruled out.

PUMPING AND MEASURING SPECIFICATIONS

All pump tests were completed using a downhole line shaft bowl pump. Power was provided by a variable-speed gasoline-powered automobile engine for the step-drawdown test. A constant-speed 30 HP electric motor (1760 rpm at 440 V) provided power during the sustained pump tests.

The pump was set in the well at 67 feet below the ground level. A 10 foot length of 4 inch diameter tubing (sucker tube) extended below the pump. The actual pumping depth was 77 feet below ground level.

Discharge measurements were estimated by timing the filling of a 5 gallon pail at a known rpm. Extrapolation of these data were used to estimate discharge at high rpm.

Temperatures of discharging fluids were measured with mercury-in-glass thermometers that were accurate to 0.2°C. Down-hole temperatures in observation wells CD-2 and JW were measured with an Envirolabs cable-reel digital thermometer with an accuracy of 0.1°C.

Water levels were measured in well CD-1 using a gas-charged 63 foot air line with a direct reading depth gauge, accurate to 0.5 foot. The air line gauge was calibrated against an electric sounding probe with an estimated accuracy of 0.1 foot. Water levels in observation wells were measured with the electric sounding probe.

AQUIFER TEST

CD-1 STEP DRAWDOWN EVALUATION

The purpose of the CD-1 step drawdown test was to determine the optimum pumping rate for the constant rate aquifer test and to calculate the initial specific capacity of the well.

Each "step" consisted of producing the well at the specified rate for 120 minutes and monitoring the resulting water level decrease. A change in rate for the next production level was accompanied by shutting off the pump, allowing the water level to surge in the well, and starting the pump at the new, increased rate.

Results from each step are summarized as follows:

STEP	PUMPING RATE (GPM)	DRAWDOWN (FT.)	SPECIFIC CAPACITY (GPM/FT.)
#1	200	5	40
#2	250	6	41.7
#3	300	7	42.9

At each step, the water level decreased within the first two minutes of production and "stabilized" at that level. The increasing specific capacity results from continuing well development.

The constant production rate selected for the aquifer test was determined by the physical limitations of the pump.

CD-1 CONSTANT RATE EVALUATION

Three separate constant rate pump tests were conducted during a 7-day period from February 17, through February 24, 1983. The production rate in each case was 255 GPM, the water temperature was a constant 80°C (178°F), and the static water level was 43 feet. A summary of each test is as follows:

DATE	TEST #	LENGTH OF TEST	MAXIMUM DRAWDOWN (FT.)	RECOVERY TIME (MIN.)	SPECIFIC CAPACITY (GPM/FT.)
2/17	1	26 hrs.	6	2	41.7
2/19	2	72 hrs.	5.5	1	46.4
2/22	3	48 hrs.	5.0	1	51.0

Specific capacity of the well in gallons-per-minute per foot of drawdown continued to increase during the three tests and results from continuing well development. This phenomenon was also observed during the step drawdown test.

Maximum drawdown during tests #1 and #2 occurred within four minutes after pump start-up. Full recovery of the water level to static condition occurred within two minutes after pump shut-down for every test. Such quick responses result from a highly transmissive aquifer.

Because of this high transmissivity, the aquifer test data cannot be analyzed to determine an exact value. Analysis of this aquifer characteristic depends on removing fluid during the pump test at a greater rate than the aquifer will deliver to the well. In this case, water could move through the aquifer at a rate at least equal to the pumping rate of CD-1. In order to obtain an exact value of transmissivity, CD-1 must be pumped at a higher rate and for a sufficient period of time to observe a gradual decline in the water level.

Results from this test indicate that CD-1 will successfully produce at least 255 gallons per minute at a constant temperature of 80°C. Considering the general hydrologic response and the gravel-type material, this aquifer could be produced at a higher rate. The exact rate cannot be quantified with this data.

OBSERVATION WELL RESULTS

Observation wells CD-2 and JW, located approximately 150 feet southeast and 600 feet northwest of CD-1, respectively, were monitored during the 7-day pump test period. The initial static water levels were measured on February 15, before any testing of CD-1. This measurement established the depth to water below the top of the casing. The actual water level elevations were not determined because well elevations were not surveyed.

Water levels recorded in both wells during the CD-1 constant rate test showed both increased and decreased levels as compared to the initial static level. These fluctuations did not result from the CD-1 pump testing. In particular, CD-2 showed a maximum increase of 0.25 feet during constant rate test #3. If the observation well had been affected by the test, a drop in water level would have resulted. Water level fluctuations in both CD-2 and JW probably resulted from barometric pressure changes during the 7-day period of observation.

TEMPERATURE GRADIENT MEASUREMENTS IN OBSERVATION WELLS

Measurements of water levels and water temperatures at specific depths were made in observation wells before, during and after pumping well CD-1 from February 15 through February 25, 1983. Data from the measurements are graphically illustrated in Figure 3. The data show the characteristic temperature-depth profile for Caliente. On February 15, 1983, well CD-2 had a maximum temperature of nearly 80°C (178°F) at a depth of 60 feet. For well JW on February 15, a maximum temperature of 80°C was measured at 80 feet. The temperature gradient configuration for both wells remained nearly constant during the first five days of pumping well CD-1. On February 22, a slight increase in temperature of 1° to 2°C was first recorded in well JW; water temperatures continued to increase throughout the well bore. On February 25, a temperature of 14°C was recorded in JW at a depth of 80 feet. A similar increase in water temperatures throughout the CD-2 well bore was also recorded. A measureable increase was first observed on February 23, and by February 25 a maximum temperature increase of 9°C was recorded in CD-2 at a depth of 80 feet.

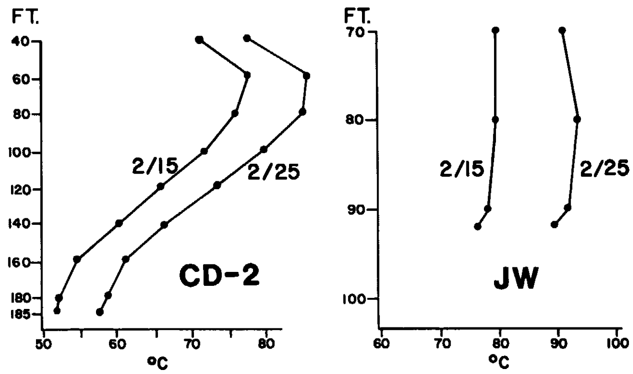

Figure 3: Temperature-depth profiles of wells CD-2 and JW before and after 10-day pump test of well CD-1.

The increase in temperature of these two wells is directly related to fluid withdrawal during the sustained pumping of CD-1. The data suggest that the highly transmissive thermal aquifer is in hydraulic continuity with a responsive recharge mechanism that can supply water in excess of 200°F. The exact location of recharge is unknown, but it appears to be related to the carbonate thrust sheet that strikes north across Antelope Canyon with a near vertical dip. Observation well JW is located very near this structure. Temperature increases in observation well CD-2, which is located nearly 1000 feet east of the thrust sheet, suggest that another structure may also recharge the shallow thermal aquifer with thermal fluids. It is interesting to note that although temperature increases were observed in both observation wells, no temperature increase was observed in the production well (CD-1).

GEOTHERMAL FLUID CHEMISTRY

A fluid geochemistry sampling program was completed during the preliminary assessment of geothermal resources in Caliente (Trexler and others, 1980). During that study, 12 fluid samples were collected and analyzed for major, minor and trace elements. The thermal waters range in temperature from 24 to 67°C and are chemically similar to one another. These data are shown graphically in Figure 4. The two chemical groups were differentiated on the basis of chemistry and geography.

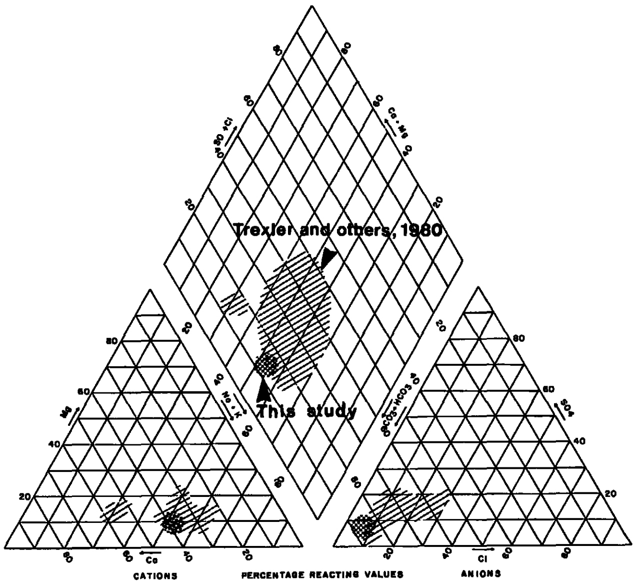

Figure 4: Chemical characteristics of geothermal fluids in Caliente.

Five fluid samples were collected at irregular intervals over the course of pump testing well CD-1. Samples were collected directly from the discharge pipe which flowed clear, sediment-free water at a constant 255 GPM at 80°C. Fluid samples were collected in clean, plastic sample bottles that had been rinsed twice with discharging fluids. All the air was eliminated from the plastic bottle prior to capping. Fluid samples were not filtered, acidified, nor diluted in the field. The samples were shipped to a commercial laboratory and analyzed for major dissolved constituents, as well as some minor and trace elements.

Analytical techniques consisted of standard laboratory procedures for analysis of dilute geothermal fluids and included atomic absorption, induction-coupled plasma, colorimetric and hot graphite atomic absorption methods.

The analytical results are in good agreement throughout the sampling period. No large-scale physical or chemical variations are observed. The water from CD-1 is sodium-bicarbonate with total dissolved solids of approximately 450 parts per million (ppm) and a pH of 7.6. The drinking water for the City of Caliente contains approximately 395 ppm total dissolved solids.

The major chemical constituents for the five samples collected during pump tests of CD-1 do not vary over a wide range and are chemically similar to fluids collected in a previous study (Trexler and others, 1980). Figure 4 compares the range of values from this study with those collected in 1980. The data points from these analyses are coincident with those from other geothermal waters from Caliente.

Temperatures of geothermal waters in Caliente range from 67°C (Wallis well) to 24°C (LDS well). Dilution of thermal waters from Meadow Valley Wash is documented in chemical variations of the fluids as well as fluid temperatures. The highest temperatures recorded in Antelope Canyon (95°C; 204°F) were measured in well JW, located approximately 600 feet west of CD-1. Although somewhat cooler (80°C; 176°F), geothermal fluids from well CD-1 probably represent relatively undiluted geothermal waters. Trexler and others (1980) concluded that thermal fluids originate in or near Antelope Canyon and are quickly cooled and diluted by mixing with waters from Meadow Valley Wash. This study supports that claim.

Water samples were collected during the pump test to ascertain the chemical continuity within the thermal aquifer and to identify possible contamination of the aquifer by a non-thermal source. No significant variation was observed in concentrations among the major cations. Some variations were observed in sulfate and nitrate, but these are believed to be related to contamination from a near-surface source. These data suggest that the thermal aquifer that produced these fluids is chemically homogeneous.

CONCLUSIONS

Direct use of geothermal fluids for district space heating has been hampered in several areas by a combination of technical and economic barriers. Technical considerations include insufficient temperature, poor flow rate, unsatisfactory water quality, and large depth-to-resource. Economic considerations are factored into each technical aspect, but are much more significant during resource development. The choice of hardware for the pumping and distribution system, the method of fluid disposal or reinjection, labor costs, and charges associated with financing represent critical decision points in the development of a geothermal resource.

This report provides a description of a geothermal resource that presents no known technical barriers to development. The two test wells are located within a mile of downtown Caliente. The temperature of the pumped fluids was 80°C (176°F), but temperatures as high as 96°C (204°F) were measured in a well 600 feet west of CD-1. The depth to the resource is 100 feet and the aquifer transmissivity is extremely high. In addition, the water quality is excellent and can be used for both space heating and domestic (potable) applications.

An engineering and economic feasibility study completed for the City of Caliente by the Oregon Institute of Technology, GEO-HEAT Center estimated that a city-wide geothermal space heating district could be developed and installed for approximately $2.5 million. This study assumed a resource temperature of 160°F and a flow rate of 850 GPM. Because the resource temperature is higher than expected, a flow rate of only 750 GPM is required.

The test results from this study strongly suggest that the resource can support the proposed geothermal space heating district.

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