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DESERT PEAK: A GEOTHERMAL FIELD IN CHURCHILL COUNTY, NEVADA

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ABSTRACT

The 400°F liquid dominated Desert Peak geothermal reservoir produces from fractures associated with intersecting north-northeast and east-northeast trending normal faults. Fractures occur in intrusive basement rocks, pre-Tertiary metasedimentary and metavolcanic rocks, and Tertiary volcanic rocks. Static temperature surveys from six deep wells indicate that the reservoir has both recharge and discharge in the vicinity of wells B21-1 and 86-21.

Interference data, from a 30-day flow test of 86-21 show high reservoir connectivity. The calculated transmissivity is an order of magnitude higher in a north-south direction than in an east-west direction. A reservoir thickness on the order of thousands of feet and disturbed reserves in excess of 7 billion barrels are estimated.

A conceptual model of the Desert Peak system contains meteoric water derived from the Carson and Fernley Sinks. Heated at depth, water rises up along normal faults into highly fractured rocks between the depths of 3000 and 9000 feet, forming a geothermal reservoir. The thermal water naturally rises or leaks out of the reservoir up normal faults to within a few hundred feet of the surface until it has reached hydrostatic equilibrium or is blocked by discontinuous impermeable lacustrine sedimentary rocks. In the latter case it spreads out laterally creating a huge near surface thermal anomaly.

INTRODUCTION

The Desert Peak geothermal field is located approximately 50 miles east-northeast of Reno, Nevada in northwestern Churchill County (Fig. 1). It underlies the northern part of the Hot Springs Mountains which form part of the northwestern margin of the Carson Sink. To date six deep wells and numerous shallow and intermediate depth temperature-gradient holes have been drilled at Desert Peak. Only one of these wells has not intersected the geothermal reservoir. These wells have discovered a liquid dominated reservoir with an average temperature of 400°F. The wells produce from depths between 3000 and 9000 feet. The produced fluid is a sodium chloride water with a total dissolved solids content of 6700 mg/l. The dissolved gas content is between .02 and .04% by weight. The Desert Peak geothermal field is blind in that there is very little geological evidence exposed on the surface to indicate its presence (Benoit et al., 1982). At the present time, the proposed field development by Phillips Petroleum Company calls for a 9 MW demonstration power plant to be built and operating by 1985.

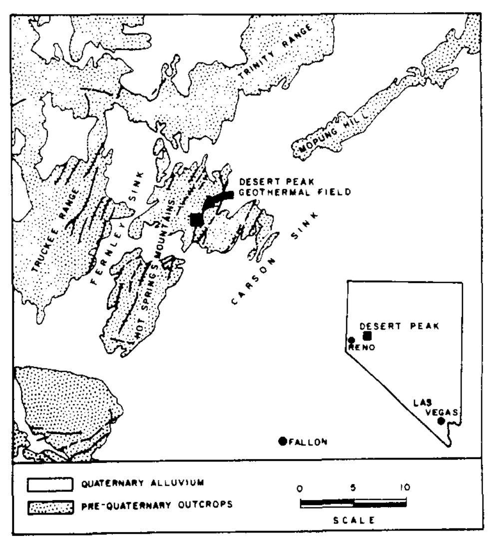

Figure 1. The Location Map.

GEOLOGY AND GEOPHYSICS

The Hot Springs Mountains are a low relief, highly fragmented horst block. In the northern half of the range, the general stratigraphy consists of intrusive rocks ranging from hornblendite to granite in composition below depths of 7000 feet. These have intruded and contact metamorphosed a Mesozoic (?) sequence of marine metasedimentary and metavolcanic rocks which lie between depths of 3000 and 7000 feet. Argillite, quartzite and phyllite are the dominant lithologies with lesser limestone and metavolcanic rocks also being present. Tertiary volcanic rocks overlie the pre-Tertiary section. This volcanic section can be broken into a lower rhyolitic unit composed primarily of ash flow tuffs and an upper basaltic unit known as the Chloropagus Formation. The combined thickness of this volcanic unit is between 2500 and 3000 feet. Overlying these volcanic rocks is a sequence of lacustrine sedimentary rocks known as the Truckee Formation which is up to 600 feet thick in the vicinity of the wells. Lastly, Quaternary alluvium and a thin veneer of windblown sand cover most of the area in the immediate vicinity of the wells.

Structurally, the northern Hot Springs Mountains have been broken into numerous rhombohedral blocks by intersecting north-northeast and east-northeast trending normal faults. Recent mapping and drilling indicates that drape folds overlie many of these normal faults in the vicinity of the deep wells. These drape folds can be exposed where well-bedded Tertiary sedimentary rocks have been preserved above an elevation of about 4500 feet. In the immediate vicinity of the wells the sedimentary rocks are either eroded or are poorly exposed so the drape folds are much more difficult to recognize. The locations of the deep wells and the faults inferred on the basis of a drape folding interpretation are shown in Fig. 2. The locations of these faults are different than those presented earlier (Benoit et al., 1982; Hiner, 1979).

Self-potential and ground magnetic surveys have been used at Desert Peak to help in locating possible hydrothermally active buried faults. The trends of both geologically and geophysically interpreted faults, as shown in Fig. 2, are similar. The elevation contours of the 400°F temperature, also shown in this figure, depict a dome with its peak around well B21-1. This indicates that the hot liquid rises up along normal faults in the vicinity of this well. Earlier reports (Benoit et al., 1982) have demonstrated that near the surface this thermal water

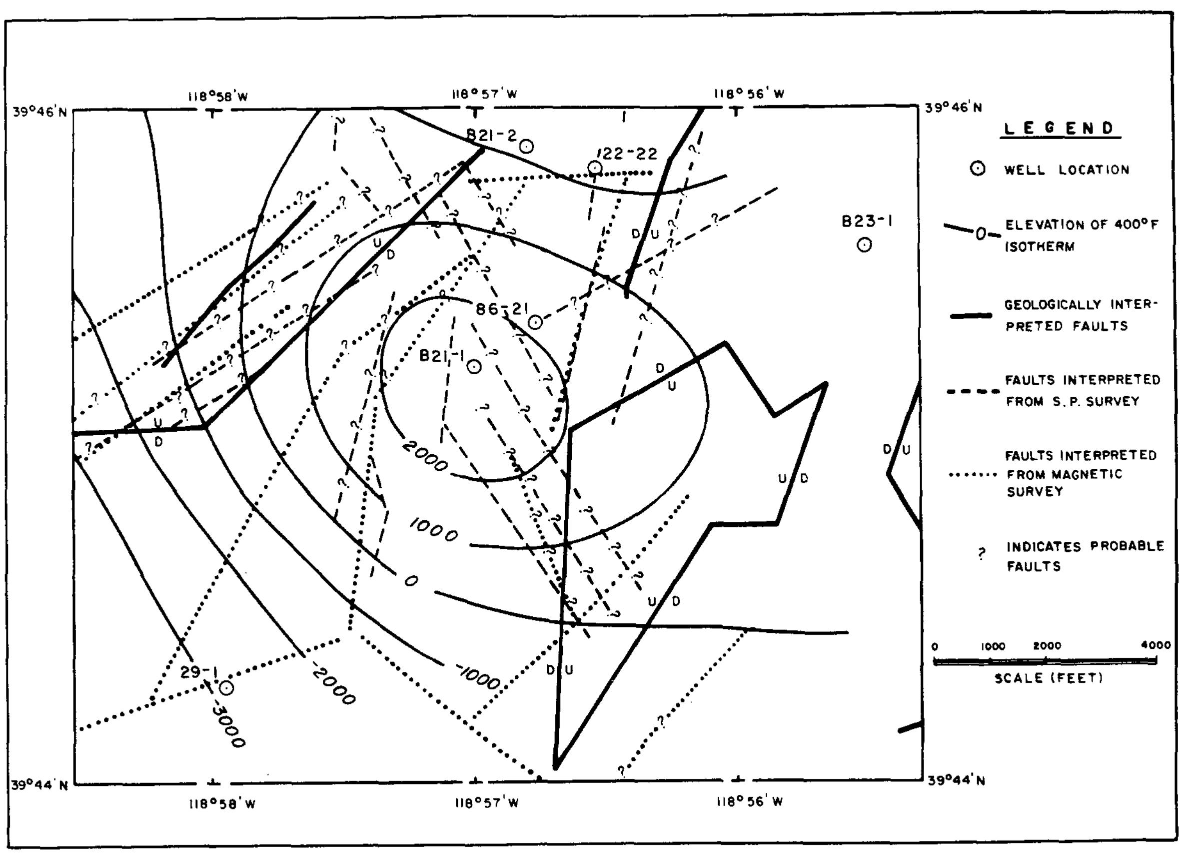

Figure 2. Inferred faults, well locations and evaluation contours of 400°F temperature in Desert Peak.

moves laterally down gradient through available permeability.

A plot of static formation temperatures versus elevation in all the Desert Peak wells is shown in Fig. 3. In a broad sense, these temperature profiles are of three types. First, wells B21-1 and 86-21 are the hottest wells at the shallowest depths with continuously decreasing temperature gradients. These wells are believed to be closer to a hot discharge zone of the system than the other wells in the field. A comparison of the deep isothermal temperatures in the wells suggests that wells B21-1 and 86-21 are also closer to the recharge source of the system than well B21-2. The isothermal temperature in B21-1 and 86-21 is 406°F compared to that of 392°F in B21-2.

The second type of profiles are those measured in wells B23-1 and 22-22.

The temperatures at shallow depths in these wells are lower than those obtained in B21-1 and 86-21, but are similar at greater depths. The profiles of the third type are the reversible temperature profiles measured in wells B21-2 and 29-1. The main difference between these two wells is that the well B21-2 intersected the geothermal reservoir while the well 29-1 is located outside the reservoir. The high temperature gradients at shallow depths in these two wells appear to have been caused by lateral flow of hot water. The reversal in 29-1 is caused by hot water originating in the vicinity of wells B21-1 and 86-21 flowing outward over colder local waters. The cause of the reversal in B21-2 needs further study.

The production zones defined from well logs and drilling reports are also shown in Fig. 3. It is believed that the well B23-1 intersects two different hot water aquifers, however only one is shown in this figure. Based on successive temperature surveys, Urban and Diment (1982) delineated a shallow aquifer between 330 and 1645 foot elevation (2950 and 4265 foot depth), as shown in Fig. 3. Well B23-1 apparently produces from below the 7000 foot depth, indicating a deeper reservoir extending below this depth. The geothermal reservoir, as presently known, in the Desert Peak area lies below an elevation of 1900 feet.

INTERFERENCE TESTING

Well 86-21 was flow tested for 30 days in the fall of 1982. It produced about 550,000 lbm/hr at an average wellhead pressure and temperature of 85 psig and 325°F respectively. A total of 1.3 million barrels of fluids was produced during this test. Wells B21-1 and B21-2, located respectively 1315 feet southwest and 3190 feet north from 86-21, were monitored for the interference data (Fig. 2).

The observation wells were equipped with downhole pressure chambers connected to high accuracy Heise gauges by capillary tubing. The monitoring system was pressurized with nitrogen to minimize response time. An hourly reading of the interference data was taken during the test. It was noticed that the wells B21-1 and B21-2 responded within 8 and 12 hours, respectively, to the flowing of 86-21. This indicates that the wells in this reservoir are well connected.

A log-log plot of drawdown versus time is shown in Fig. 4 for both wells. A maximum pressure drop of about 34 psi was noted in well B21-1 and that of about 12.5 psi in well B21-2. The line source solution match of the field data and the nondimensional coordinates of the matched point are also shown in this figure.

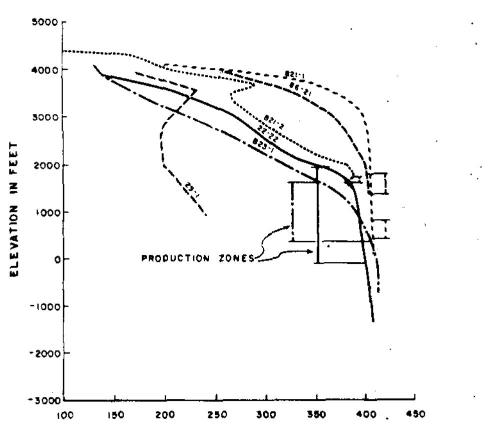

Figure 3. Static temperatures in Desert Peak Wells.

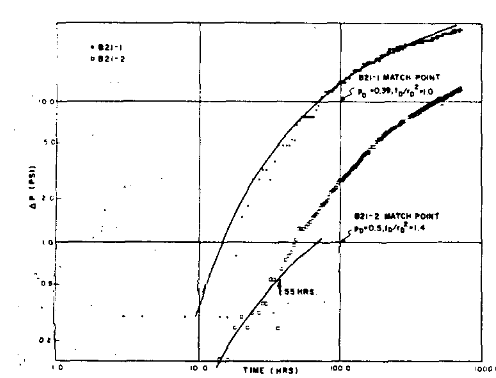

Figure 4. Drawdown-type curve match for Wells B21-1 and B21-2.

The Horner buildup plots of both wells are presented in Fig. 5. The data of the well B21-1, shown in Figs. 4 and 5, do not point toward the existence of a permeability barrier. However, the plots of the well B21-2 do display the existence of a discontinuity after 55 hours during drawdown and 142 hours during buildup.

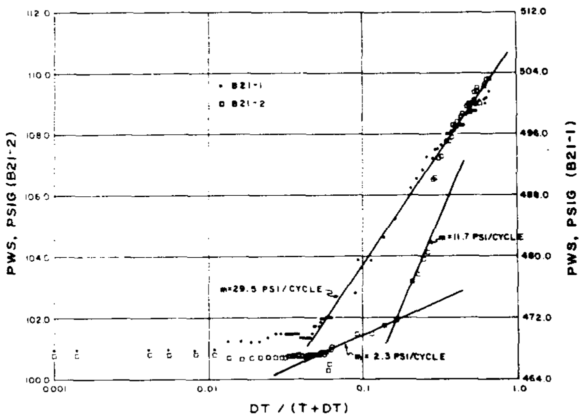

Figure 5. Horner buildup plots for wells B21-1 and B21-2.

For an average production rate of 550,000 lbm/hr and a reservoir temperature of 405°F, the following reservoir parameters may be obtained from Figs. 4 and 5 (Earlougher, 1977).

Observation Well B21-1

Drawdown: $kh = 33,000$ md-ft
$\phi C_t h = 37 \times 10^{-4}$ ft/psi

Buildup: $kh = 33,000$ md-ft
$\phi C_t h = 27 \times 10^{-4}$ ft/psi

Observation Well B21-2

Drawdown: $kh = 423,200$ md-ft
$\phi C_t h = 57 \times 10^{-4}$ ft/psi
distance to the discontinuity 5600 feet

Buildup: $kh = 423,800$ md-ft
$\phi C_t h = 70 \times 10^{-4}$ ft/psi
distance to the discontinuity 8150 feet

These results imply that the thickness of the reservoir is in thousands of feet rather than hundreds of feet. Based on the interference data, the reserves disturbed during the 30-day flow exceed 7 billion barrels. Northeast-southwest trending faults located north of well 22-22 may be interpreted as possible permeability barriers.

CONCEPTUAL MODEL

A conceptual model of the Desert Peak geothermal field is shown in Fig. 6. The depth of the upper mantle in the Basin and Range province varies from 15 to 20 miles (Stauber, 1983). Previously discussed stratigraphy and the thicknesses of various formations encountered in this field are also shown in this figure.

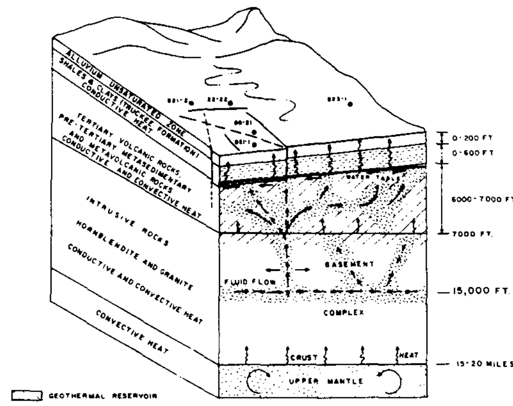

Figure 6. Conceptual Model of Desert Peak Geothermal Field.

The fractures in hard basement rocks which result from normal faulting are expected to increase vertical permeability much more than the horizontal permeability. The heat transfer mechanism in the basement complex is expected to be controlled by convection in open fractures and by conduction in low permeability rocks. Well B23-1 is believed to produce from the granite below 7000 feet.

Wells B21-1 and B21-2 produce from the pre-Tertiary section. Well 86-21 produces from rhyolite near the bottom of the Tertiary volcanic section where both vertical and horizontal water flow has been observed. In the Tertiary volcanic section, heat transfer is primarily by convection. It is presumed that heat transfer in the pre-Tertiary metasedimentary and metavolcanic rocks is by both convection and conduction depending upon the presence or absence of fluid movement. The known geothermal reservoir is shown schematically by hatched lines in Fig. 6.

Fine grained lacustrine sedimentary rocks of the Truckee Formation overlie Tertiary volcanic rocks and act as local caps for near surface horizontal movement of thermal water. However, in many areas the water table is several hundred feet deep. This means that often the relatively thin Truckee Formation does not have a chance to act as a cap rock because it is completely above the water table. At this time, it is not known whether or not an effective cap exists for the Desert Peak reservoir.

The uppermost layer in Fig. 6 consists of alluvium to a maximum depth of 200 feet. This layer is almost always above the water table.

The reservoir is highly fractured with faults concentrated in northeasterly and northwesterly directions, as shown in Fig. 2. Faults shown in Fig. 6 are schematic, but do represent the reservoir concept as known to date.

In summary, the vertical as well as horizontal permeability in the basement and in the geothermal reservoir is mostly due to fractures. The major source of fluids in the Desert Peak area is thought to be seepage from the Carson and Fernley Sinks, which are located respectively to the east and west of the Hot Springs Mountains (Fig. 1). It is postulated that this water percolates gradually into the sediments and basement rock over an area considerably larger than the Desert Peak anomaly. Heated at depth by an as yet undefined source, the liquid rises into the high permeability fractured fault zones, convecting energy toward the surface. The ascending hot water charges the highly fractured main geothermal reservoir which is believed to exist between 3000 feet and 9000 feet depth. The thermal water either continues to rise or leaks out of the reservoir to within a few hundred feet of the surface until it has reached hydrostatic equilibrium or it is blocked by impermeable lacustrine sedimentary rocks. In the latter case, it flows laterally down gradient along available flow path permeability between depths of 200 to 1000 feet. This lateral hot water flow has created a huge, intense near-surface thermal anomaly which obscures the location of the smaller actual produceable reservoir (Fig. 3). It is believed that the three shallowest producing wells (B21-1, B21-2 and 86-21) produce from normal faults concealed by overlying drape folds.

CONCLUSIONS

Geological and well testing data indicate that the fractured geothermal reservoir lies in various rock types. The fractures, at least in the immediate vicinity of wells B21-1, B21-2 and 86-21, display a strong north-south trend. The interference data indicates that the wells intersect a highly permeable reservoir. The north-south transmissivity is an order of magnitude higher than that in east-west direction. This agrees well with the fault orientation in the field. The transmissivity and storativity calculations indicate that the thickness of the Desert Peak reservoir is on the order of thousands of feet. This agrees well with the interpretation that the fracture zones are associated with steeply dipping normal faults. A conceptual model, involving deep circulation of meteoric water through normal faults, explains various features associated with the Desert Peak geothermal reservoir.

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