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DISCLAIMER

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ABSTRACT

The Bureau of Reclamation and Lawrence Berkeley Laboratory have collaborated on a resource evaluation project at Susanville, California. The project has included drilling exploratory wells, well logging, subsurface geological studies, hydrothermal measurements, and numerical calculations. The studies show that the portion of the resource above 40°C is partially confined both laterally and vertically. The areal confinement is on three sides of the northwest trending anomaly. The total areal extent to the northwest has not yet been determined. The vertical confinement appears to be related to the presence of fractures at the agglomerate-basalt interface in the southern portion of the anomaly. Well tests show a high permeability and low storativity (in general), which are consistent with a fracture dominated flow system. Cores from newly drilled wells also show large numbers of fractures with relatively small matrix permeability.

INTRODUCTION

The Susanville geothermal anomaly is located in the Susanville-Honey Lake KGRA in Northeastern California. Since the 1920's warm shallow water wells and natural hot springs have been in use for space heating, heating a swimming pool, and various other domestic and low temperature industrial uses. Increased fossil fuel cost and the high cost of transporting liquified natural gas to the area has stimulated interest in developing the geothermal resource for a city-wide space heating system.

Extensive geological and geophysical resource identification has been undertaken by the Bureau of Reclamation in the Susanville-Honey Lake KGRA. (1,2,3) Geological surface mapping has also been completed. (4) The Susanville geothermal anomaly is located at the intersection of three geologic regimes, the Sierra Nevada range to the southwest, the Modoc plateau (Flood Basalts) to the northwest and a portion of the Basin and Range province which extends eastward into Nevada. The subsurface geology is characterized by interbedded mudflows, flood plain basalts and alluvial conglomerate. The surface structure indicates extensive block faulting with the dominant trend of the faults being in a northwesterly direction.

WELLS IN THE CITY OF SUSANVILLE

Six old wells are in the Susanville area, five drilled in the 1920's and one drilled in the early 1960's. Of five temperature gradient holes drilled, four (TG-1, TG-17, TG-18, TG-19) were completed to a target depth of 46m. All of the TG holes, except TG-17 and TG-2 penetrated interbedded volcanics and sediments. The Bureau of Reclamation drilled ten exploratory holes in 1978 and early 1979 within the city boundary, (Suzy 1 to 10, Figure 1), ranging in depth from 135m to 640m. Figure 2 shows a schematic of the completion records for wells Suzy 1 to 6 and some of the older wells in the area.

Several wells, drilled in the 1920's to 1930's are within the city limits. These wells, (Naef well, LDS church well, Roosevelt swimming pool well, and Wes Davis well) have been used intermittently for nearly fifty years. These wells have been used primarily for space heating, domestic hot water, and low temperature industrial purposes. Because these wells were drilled long ago, no detailed information is available on their completion, open interval, lithology and total depth. The information is summarized in Figure 2.

Detailed interpretations of the lithology encountered from drilling, cuttings, cores and geophysical well logs are being analyzed. However, in summary, most of the wells penetrate alternating layers of basalt and mud-flow (ash flow) agglomerates. Some wells also encountered alluvial conglomerates. Correlation of lithological strata from one well to another indicate probably normal faulting which coincides with the surface evidence of faults in the area. (4) Electrical logs suggest possible fracturing at the upper and lower limits of the basalt layers indicating these basalt layers, as well as the agglomerates and conglomerates may be potential reservoir units.

TEMPERATURE DISTRIBUTIONS

Temperature profiles in some of the wells are shown in Figure 3. Several of the wells, notably those in the southwest portion of the reservoir, display temperature reversals with depth. The reversals take place at depths between 100-150m in the wells with higher temperatures. Maximum temperatures range from 35°C to >70°C. The hottest well, drilled thus far, is Suzy 9. No temperature reversal takes place indicating the possibility of still higher temperatures at depth. However, the producibility of the material below the total depth of this well is as yet unknown. Further drilling and well testing in this area will indicate the producibility of these lower zones. Temperatures at depths below ground surface in the wells are contoured in Figure 4 along lines A'A and B'B in Figure 1. The temperature reversals in the southwest area of the resource are evident. Temperature contours show that the hydrothermal anomaly deepens to the northwest. Static water levels in the wells range between 2.3m to 15.5m below the ground surface.

RESERVOIR TESTING

A well test was carried out by LBL in December 1978. The test consisted of pumping three wells that are in use for heating loads. Both old and new wells were monitored. Data from recently drilled wells was ambiguous as compared to data from the older wells. In all, eight observation wells and one production well were monitored. The well test consisted of four segments. The first segment consisted of measuring background data prior to pumping the Davis well. However, due to the extremely cold weather the L.D.S. Church well was produced for space heating. To avoid and/or minimize any transients associated with church well flow, the rate was held constant at approximately 90 gpm throughout the background data collection period and the subsequent pumping of the Davis well. The second segment of the test consisted of pumping the Davis well at a rate of 250 gpm for a period of 9 days. The well was then shut in and the build-up was observed. Several days after the Davis well was shut in, the L.D.S. Church well was shut in for twelve hours; then pumped again for several days; shut in for twelve hours; and then pumped continuosly for the duration of the test. During the last segment of the test the Roosevelt swimming pool was pumped at a rate of ∿275 gpm for three days and then shut in. The magnitude of drawdowns at the observation wells in this test were from .3 m to 1.5 m (.4 to 2.4 psi). The wells with 2-inch casing were instrumented with nitrogen-filled tubing (Suzy 1, Suzy 2, Suzy 3 and Suzy 5). Well Suzy 4 was instrumented with a downhole paroscientific pressure transducer, LLB-2 was instrumented with a Hewlett Packard downhole transducer. The Naef well was instrumented with continuously recording water level gauge.

Several months of background data at the Naef well were obtained prior to the test by the Bureau of Reclamation. This is shown in Figure (5). As can be seen, there are daily fluctuations of ±.2 ft superimposed on larger magnitude fluctuations throughout the summer months. Particularly curious is the water level build-up that took place over several weeks in the early fall. At the present time the cause is unknown. However, several possible explanations exist: if rainfall were particularly heavy during this period (precipitation data has not been received to date) influx of this water from either overlying sediments or the river could cause this behavior. Another explanation could be that the cessation of irrigation after the summer months has caused a pressure build-up in the reservoir. Both of these possibilities are highly speculative, but pressure data does indicate that the reservoir is affected by external sources.

WELL TEST DATA ANALYSIS

The data were analyzed in two parts. The drawdown at the Naef well caused by the Davis well was analyzed assuming that the production of the church well has no pressure transient associated with it during the Davis well production. Analysis yields a kH/μ values of 2.3×10^6 md-ft/cp and ϕcH of 7.2×10^{-4} ft/psi. Figure 6 shows the best match obtained between the observed and calculated response. The best match of observed and calculated values indicate that the pressure response was influenced by an impermeable boundary. The results of observation well analyses are summarized in Table 1.

Pressure data in the Davis well was obtained for the duration of the test. This data was analyzed by the Miller-Dyes-Hutchinson (semi-log) technique. (5) The data are shown plotted on semi-log paper in Figure 6. After the first several hundred minutes the data fall on a single straight line indicating that no boundary is influencing the pressure response. The calculated transmissivity is 7.3×10^5 md-ft/cp. This number is substantially lower than those obtained from the analysis of the interference data. Since the producing strata of the resource and the thickness of the producing interval(s) in this well are unknown, it is difficult to ascertain the meaning of the discrepancy. However, the low transmissivity may indicate that the effective reservoir thickness sampled by the production well is less than that sampled by the observation wells. The value obtained for the transmissivity from this test is in close agreement with the value obtained from a similar test performed by the Bureau of Reclamation in 1976. (3)

CONCLUSION

The Susanville anomaly is larger in lateral extent than first estimated. Further drilling in this area since the December 1978 test has uncovered heated fluids in areas north of the original test. These wells have yet to be tested, therefore, the amount of fluid in place cannot be estimated at this time. One new well recently drilled encountered fractures below 600 ft. To what depth this fractured zone extends has not been determined.

Well testing in the southern portion of the anomaly indicated strata of high permeability.

However, this area illustrates temperature reversals at depth. Maximum produced water temperatures will depend on the ratio of vertical to horizontal permeabilities.

Prior to large scale development a more complete knowledge and understanding of the resource must be obtained. Those strata which constitute the "hot" producing zones must be identified so wells can be completed in such a way as to avoid cold water influx into the wells. The existence (or lack) of confining strata must be established. It must be known whether long term production will cause migration of cooler fluids through or from the confining strata into the producing aquifer. If the "hot" fluid formation is of limited lateral extent, it must be established whether colder fluids will flow into the hotter areas due to the pressure decline in the area of the producing well(s). Regional flow patterns must be established to ascertain optimal locations for production and injection wells (if reinjection is chosen as the fluid disposal method).

ACKNOWLEDGEMENTS

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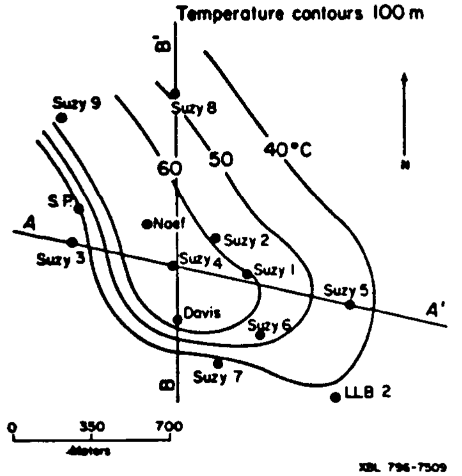

Figure 1. Well location map and temperature contours at 100m depth, Susanville, CA.

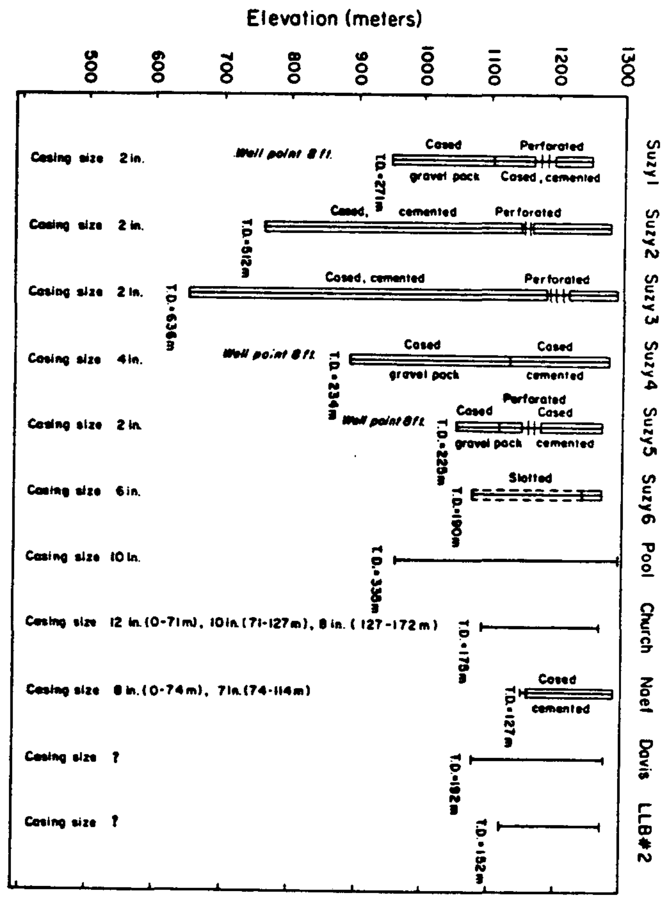

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Figure 2. Well completion for some of the wells in the City of Susanville, CA.

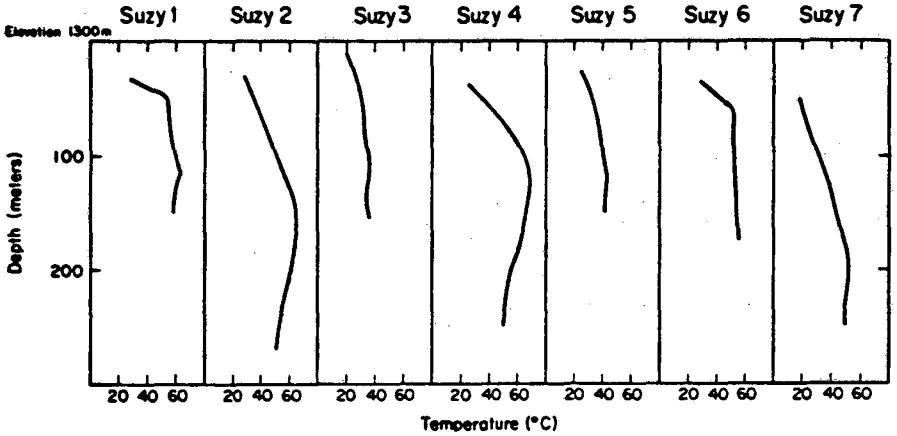

Figure 3. Temperature profiles for wells Suzy 1 to Suzy 7.

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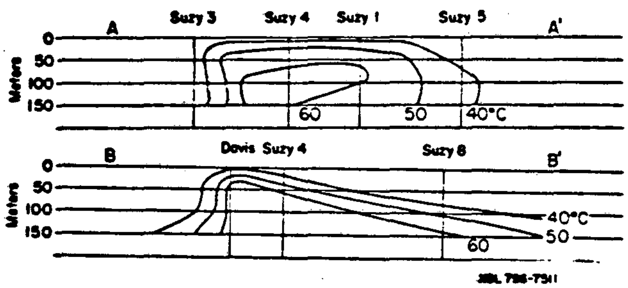


Figure 4. Cross sections of the temperature contours in the Susanville anomaly, lines A'A and B'B (see Figure 1).

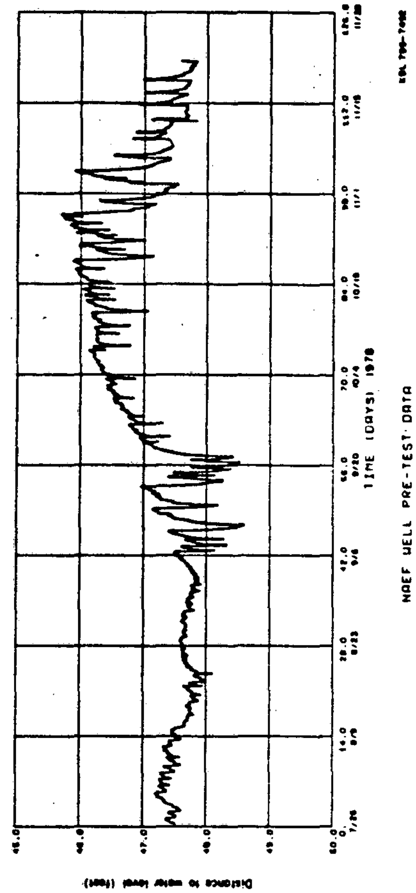
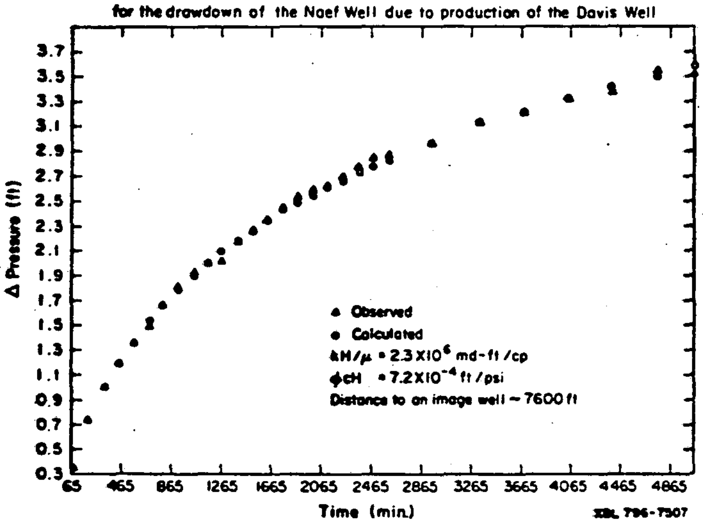


Figure 5. Naef well pre-test water-level data.

Figure 6. Match of calculated and observed values for the drawdown of the Naef Well due to production of the Davis Well



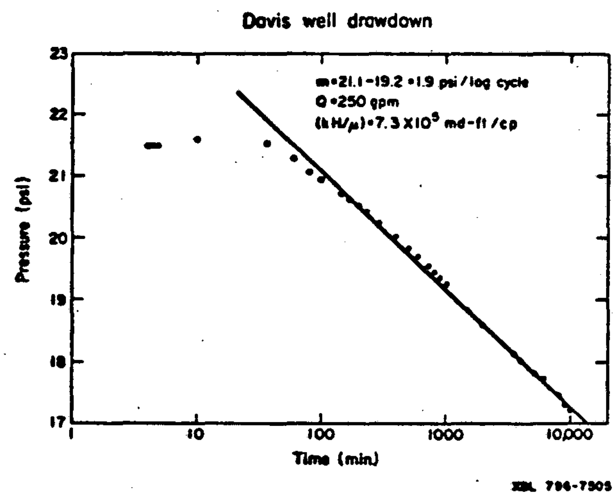


Figure 7. Semi-log plot of the Davis well drawdown.

Table 1

Observation Well	Pumped Well	$KH/(\frac{md\text{-}ft}{cp})$	ϕch (ft/psi)	Reservoir Boundaries
Naef	Church	3.6×10^6	2.3×10^{-4}	Barrier Boundary
Naef	Davis	2.3×10^6	7.2×10^{-4}	Barrier Boundary
Naef	Swimming Pool	3.4×10^6	3.9×10^{-2}	None
Davis	Davis	4.3×10^5	Not obtained	None

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