DOWNWARD CONTINUATION OF TEMPERATURE GRADIENTS AT MACFARLANE'S HOT SPRING, NORTHERN NEVADA

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ABSTRACT

MacFarlane's Hot Spring is located on the eastern margin of the Black Rock Desert of northwest Nevada. Detailed temperature logs from thirty-eight shallow boreholes (500 feet) and six intermediate depth boreholes (1500-2000 feet) have been used to construct a temperature gradient contour map covering approximately 144 square miles, both within and adjacent to the geothermal area. These temperature gradients were then continued downward through a detailed conductivity model to complete the three-dimensional thermal picture. The principal results are as follows: (1) The maximum measured temperature is 178°F at 2,000 feet, and the maximum projected temperatures at greater depths are not likely to exceed the 250-350°F range. (2) The area of hydrothermal activity is confined to the western front of a structural platform bounded by two roughly parallel normal faults. (3) The anomaly is best explained in terms of a simple groundwater flow model. The groundwater flows west through the structural platform and ascends when it intersects the conduit provided by the fault. The faults on the eastern side of the platform permit recharge to the system.

INTRODUCTION

The MacFarlane's Hot Spring geothermal prospect is located in the basin and range province in Northwest Nevada (Figure 1). It is within the "Battle Mountain High" heat flow province of Sass et al (1981) and is located about sixty miles west of Winnemucca and twenty miles east of the Double Hot Springs KGRA. The geology of the area is typical of that found throughout the Basin and Range and has been described in detail by Sibbett et al (1982). To summarize, the study area lies on an alluvial fan to the west of the Jackson Mountains (Figure 1). These mountains are lithologically characterized by Permian volcanics (the Happy Creek Volcanic series) which are overlain by sedimentary and volcanic rocks of Triassic and Jurassic age. A single, major thrust sheet containing Cretaceous and younger rocks overlies this Mesozoic sequence. Several high-angle, normal faults are present in the area and juxtapose formations of contrasting lighology and age.

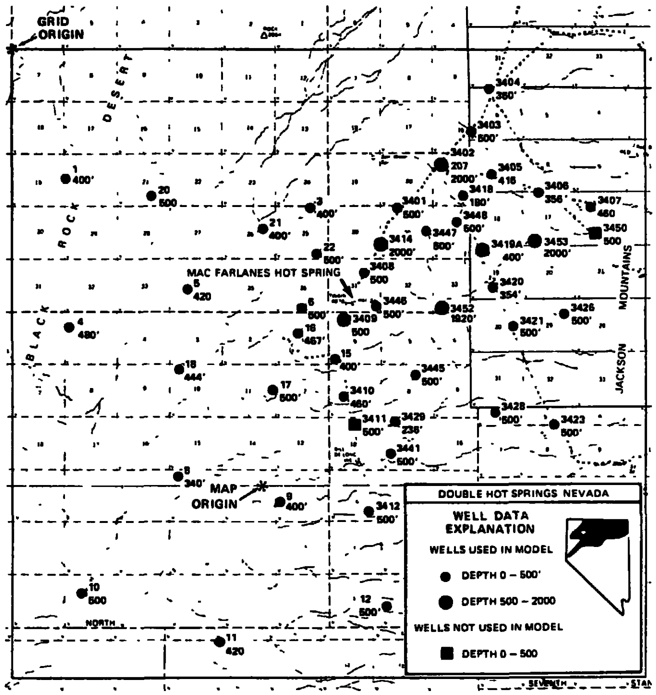

Figure 1. Location of MacFarlane's Hot Spring geothermal prospect, Nevada. Map origin is at 41° N. Lat. and 118° 45' W. Long. The shaded area in the inset is the Battle Mountain high heat flow province.

The fan, which includes most of the study area, is composed of Quaternary alluvial deposits. Two long, normal faults cross the study area in a northeast to southwest direction and define the structural platform mentioned above. Between these two faults, an inselberg of Tertiary basalt is exposed (Figure 2).

DATA PREPARATION

The technique of downward continuation as applied to temperature gradient data has been described by Brott et al (1981). The estimation of subsurface temperatures by this technique requires two basic sets of information. The

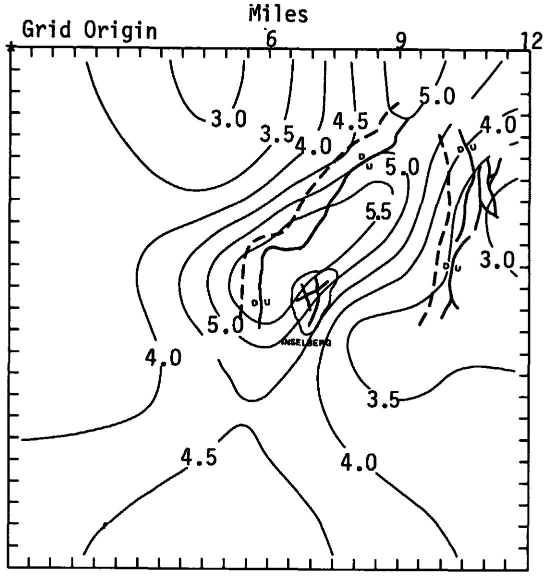

Figure 2. Low-order polynomial fit (trend surface) to temperature gradients (°F/100'). Also shown are surface faults (solid lines) and subsurface extension of these faults (dashed lines).

first is a set of near-surface temperature and thermal gradient data corrected to a common datum and contoured over the region of interest. The second set of information is a three-dimensional thermal conductivity model underlying the prospect area. The former data set is based on temperatures measured in shallow boreholes and, for the present study, corrected for topographic effects. The conductivity model is based on laboratory measurements of well cuttings and information about the lithology and structure of the region.

The locations of the forty-four boreholes used in this analysis are shown in Figure 1. Two shallow boreholes (3411 and 3450) were not included in the analysis because the temperatures were clearly disturbed by groundwater movement and provide no reliable estimate of regional heat flow (see Figure 3). The surface temperatures and gradients were taken as the midpoint of the deepest zone which exhibited clear evidence of conductive heat flow. In addition to the surface temperatures and gradients which were taken from the individual well logs, background values were assigned to represent those areas which were outside the data set yet within the perimeter of the grid model. Proceeding clockwise from the grid location (Figure 1), the assigned corner gradients are 3.7, 4.6, 4.4, and 4.4°F/100', and the assigned temperatures are 58.5, 64.1, 87.3 and 65.4°F.

All of the data from the MacFarlane's Hot Spring prospect have been corrected for topographic effects out to a distance of 1.25 miles or roughly ten times the average hole

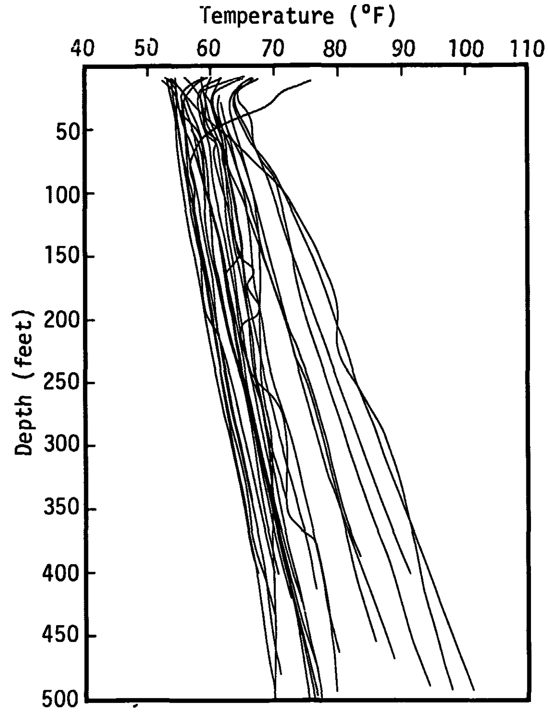

Figure 3a.

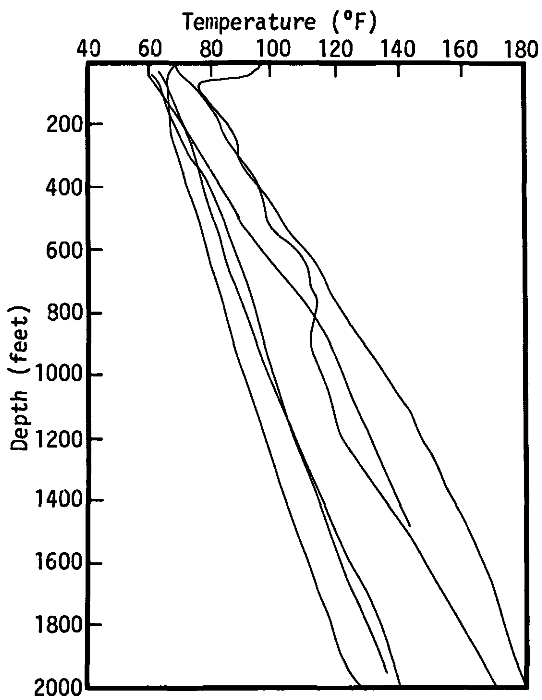

Figure 3b.

Figure 3. Composite diagram showing temperature measured in the boreholes used in the analysis.

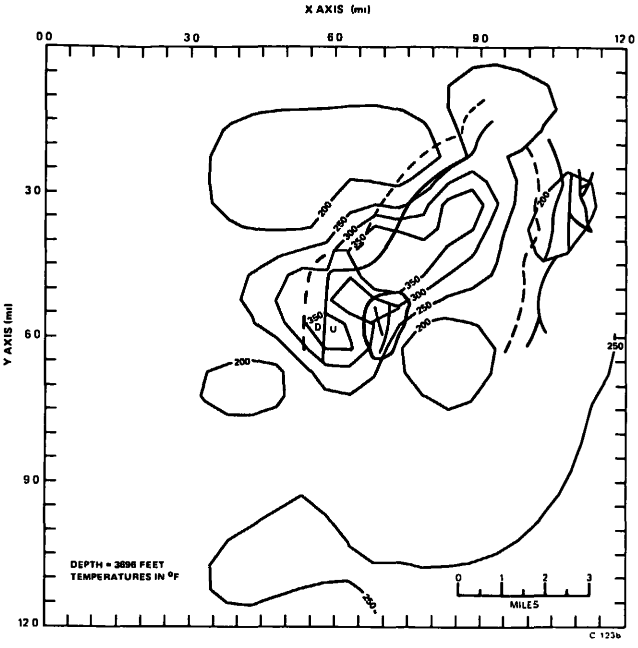

Figure 4. Temperatures continued downward to a depth of 3696 feet, the maximum depth for stable continuation. Also shown are the surface faults (solid lines) and subsurface extension of these faults (dashed lines).

depth. A lapse rate of -0.44°F/100' (-8.00°C/km) was used in the calculations. This lapse rate, which describes the linear decrease in surface temperature with increasing elevation elevation, was obtained by a least-squares approximation to the elevations (well collar) and surface temperatures (extrapolated from the temperature-depth data) of the forty-four boreholes used in this analysis. The topographic effects are small. The mean correction is 0.19 ± 0.61% with a range of -0.87 to 2.33%. The near-zero average means that the boreholes are evenly distributed throughout the topography.

The conductivity values are generally assigned in such a way as to match the known geology as closely as possbile while still maintaining a relatively simple model. In the present case, however, all of the rock units encountered in the boreholes, including Tertiary basalts as well as Quaternary alluvium, have very nearly the same thermal conductivity (3.75 mcal/cm-sec-°C). This conclusion is based on almost 200 individual conductivity values obtained using standard, divided bar techniques and well cuttings from the boreholes. No attempt, therefore, was made to vary the conductivity in the lateral direction. The conductivity values were varied with depth, however, due to the progressive decrease in porosity resulting from overburden pressure. The conductivity values have been systematically varied from 3.75 mcal/cm-sec-°C at the surface to 5.4 mcal/cm-sec-°C at a depth of 7,000 feet.

RESULTS

Most of the temperature logs available for study show strong evidence of conductive heat transfer (Figure 3) making this area an ideal place for applying the principles of downward continuation. Only two boreholes show evidence of groundwater movement (Figures 1 and 3), and both were deleted from the data set prior to the analysis. Of the undisturbed boreholes, the measured temperature gradients ranged from 2.85 to 10.36°F/100' (52-189°C/km) with an average gradient of 4.7°F/100' (86°C/km). The lowest gradients are found in the recharge areas on the flank of the Jackson Mountains where the average gradient is 2.97°F/100' (54°C/km, including the disturbed borehole 3450), (Figure 1). The maximum gradient of 10.36°F/100' represents borehole 3408 located one-half mile north of MacFarlane's Hot Spring. The average gradient for the non-geothermal portion of the Black Rock Desert on the western side of the study area is 3.97°F/100' (72°C/km). The geothermal area as defined by the 5.5°F/100' contour includes 11 square miles.

Figure 2 shows a low-order polynomial fit to the measured surface temperature gradients (trend surface) and the principal mappable structural features within the study area. The purpose of this figure is to demonstrate the close association between the geothermal anomaly and the regional structural setting. This correlation almost demands a cause-effect relationship. The region of elevated temperature gradients is confined to the western front of the structural platform located between the two northeast trending fault systems, and the maximum gradients are consistently located over the westernmost fault. Another interesting aspect of Figure 2 is that the gradients return to normal at the southern end of the westernmost fault. These observations, coupled with the low gradients observed over the fault system of the eastern margin of the platform, form the basis of our hydrology model to explain the origin of the MacFarlane's Hot Spring geothermal system.

Figure 4 shows the results of the downward continuation analysis. The downward continuation was terminated at 3696 feet (0.70 miles). Below this depth, oscillations started to occur indicating that the source depths had been encountered. As shown in Figure 4, the maximum temperature that is likely to be encountered is 350°F, and a value of 300°F is probably more realistic. The maximum temperatures predicted by chemical geothermometry are near 280°F (Sibbett et al, 1982).

The origin of the MacFarlane's Hot Spring geothermal area is most easily explained in terms of a simple groundwater flow model. This is shown schematically in Figures 5 and 6. The high-elevation region near the eastern fault complex is an area of groundwater recharge as

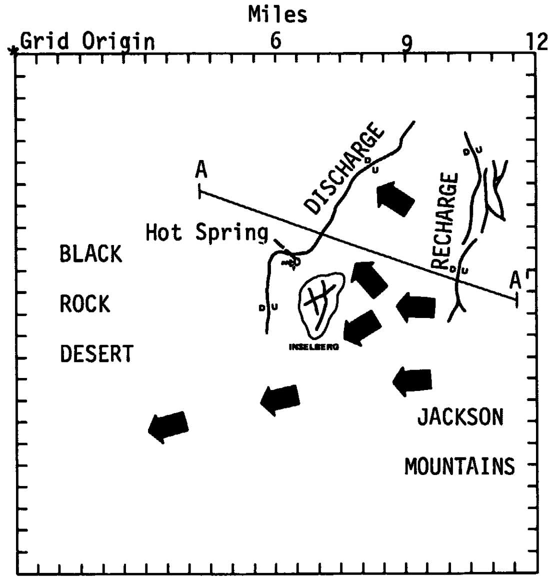

Figure 5. Proposed model for MacFarlane's Hot Spring geothermal system. Arrows refer to direction of groundwater flow.

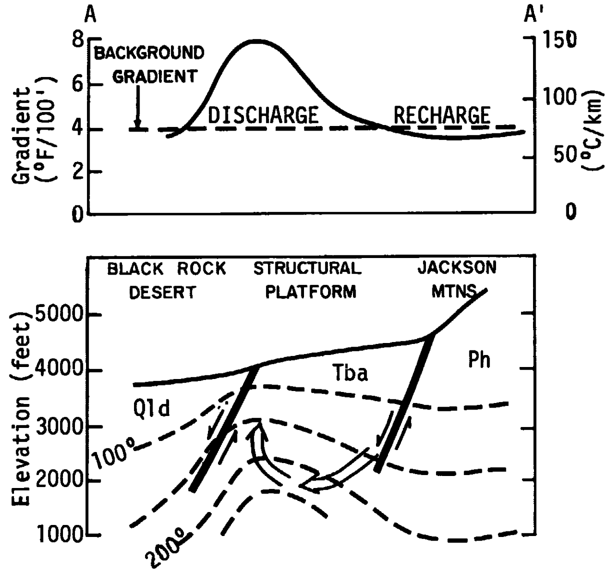

Figure 6. Proposed model for MacFarlane's Hot Spring geothermal system. (Top) Temperature gradients. (Bottom) Isotherms, faults, and assumed groundwater flow paths. Qld, Tba, Ph are respectively Lake Lohantan deposits, vesicular basalt flows, and the Happy Creek group (Sibbett et al, 1982).

evidenced by the low surface gradients (Figure 2) and the presence of the isothermal borehole 3450 (Figure 1). Meteoric water enters the hydrologic system via these faults and flows westward through aquifers which are comprised mostly of porphyritic and vesicular basalts (Sibbett et al, 1982). At the inselberg, a topographic high of several hundred feet, the flow is diverted to the northwest and southwest. To the northwest, the flow intersects the conduit provided by the fault and is free to ascend to the surface at MacFarlane's Hot Spring and forms the shallow geothermal system. To the southwest, the fault is not encountered, and the groundwater continues into the Black Rock Desert without forming a geothermal system.

ACKNOWLEDGEMENTS

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