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STRUCTURE, PERMEABILITY AND PRODUCTION CHARACTERISTICS OF THE HEBER, CALIFORNIA GEOTHERMAL FIELD

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ABSTRACT

The three key permeability elements of the Heber reservoir are; "capping" clays above 1800', a sedimentary "matrix permeability" reservoir from 1800'-5500', and fracture permeability in indurated sediments below 5500'. The fractures are related to NW trending strike-slip faults and NE trending normal faults. Maps and cross sections with dipmeter, lost circulation, temperature and Kh data illustrate the structures and their control on the movement of thermal waters. Production creates a strong initial pressure decline in the field that rapidly stabilizes. The long-term pressure decline is predicted to be low (less than 5%). Temperature data show that current development is north of the source of the thermal plume. Reservoir modeling indicates that reservoir pressures will support further development.

INTRODUCTION

This paper presents data gathered by Chevron in the Heber geothermal reservoir between June, 1984 and December, 1986 during development drilling, initial well testing and the first year of production of the Dravo 52 MW dual flash plant and the SDGE 67 MW binary plant. Fifteen wells had been drilled during the exploration and evaluation phases of work at Heber (Figure 1). Beginning in 1984, nine production wells and seven injection wells were drilled for the Dravo plant and seven production wells and five injection wells for the SDGE plant. In addition, two temperature gradient wells (GTW 4 & 6, Figure 1) were drilled in 1986 to assess the development potential of the southern portion of the field.

Prior to the development drilling, the Heber reservoir was thought to be a fairly homogeneous pile of deltaic sediments, with porosity and permeability decreasing with depth according to the normal induration effects. Production was expected to come from primary matrix permeability of the sediments (Cooper and Salveson, 1982 and Lippman and Bodvarsson, 1983). The development wells were designed to produce fluid from four 2000' thick zones to balance withdrawals over the entire depth range of the sedimentary reservoir. However, the results of the development work show that the reservoir has three major permeability units (Figure 2); "capping" clays from 500-1800', high matrix permeability sandstone "outflow" reservoir from 1800'-5500', and high permeability "feeder" faults and fractures in indurated sediments below 5500'.

This revised reservoir model is being used in planning future development well locations.

RESERVOIR CHARACTERISTICS

The key permeability elements of the Heber reservoir can be seen on the seismic line in Figure 3. The capping clays stand out as strong reflectors from above approximately 1800'. The shallow sedimentary reservoir is represented by the reflectors seen down to approximately 5500'. The poorly reflective zone below 5500' represents the heavily indurated sediments. These sediments are cut by two fault trends; a NW trending right lateral strike-slip zone and a NE trending normal fault on the west. This structural and permeability setting is repeated to the north through the heart of the field as shown by the dipmeter data from the wells on cross section A-A' (Figure 4).

The structural control on permeability is also evident on a map of lost circulation (Figure 5). Here we see that the NW striking right lateral strike slip fault and NE trending normal fault are clearly outlined by the lost circulation contours. These trends of faulting are to be expected in the Salton Trough, repeating the patterns of regional faulting shown on Figure 6.

The temperature distribution of the field illustrates the control that the permeability structure and regional groundwater flow have on the movement of thermal fluids. Temperature isotherms at 6000' (Figure 1) show that the center of the rising thermal water movement is in the southern portion of the field. The maximum temperature measured in the field to date is 390F. Temperature cross section A-A' (Figure 7)

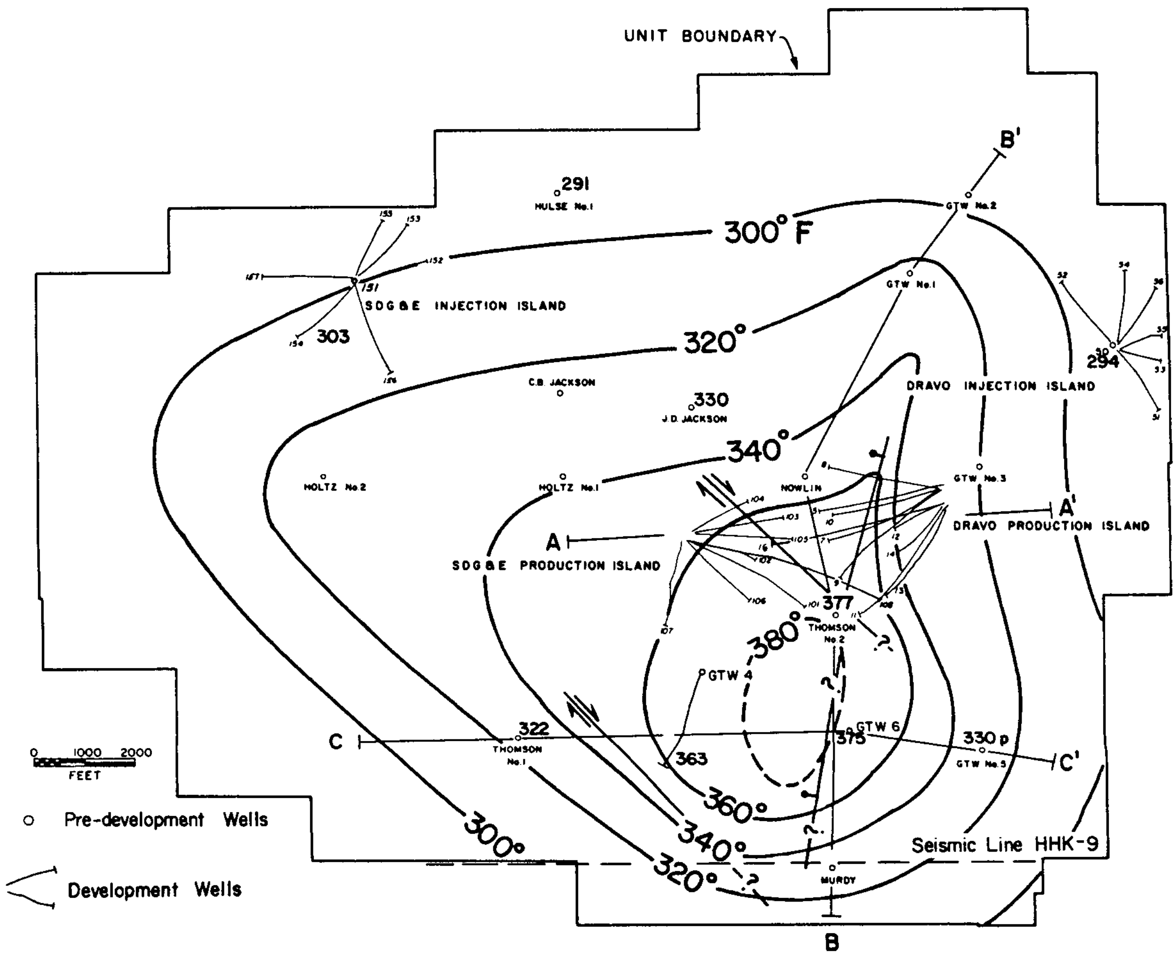

Figure 1. Well locations, structure, and temperature contours at 6000 feet.

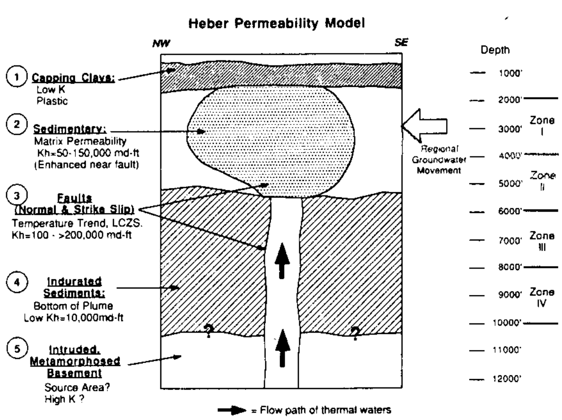

Figure 2. Heber permeability model.

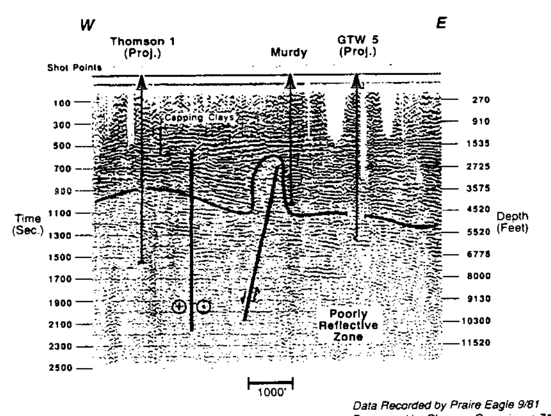

Figure 3. Seismic line HHK-9.

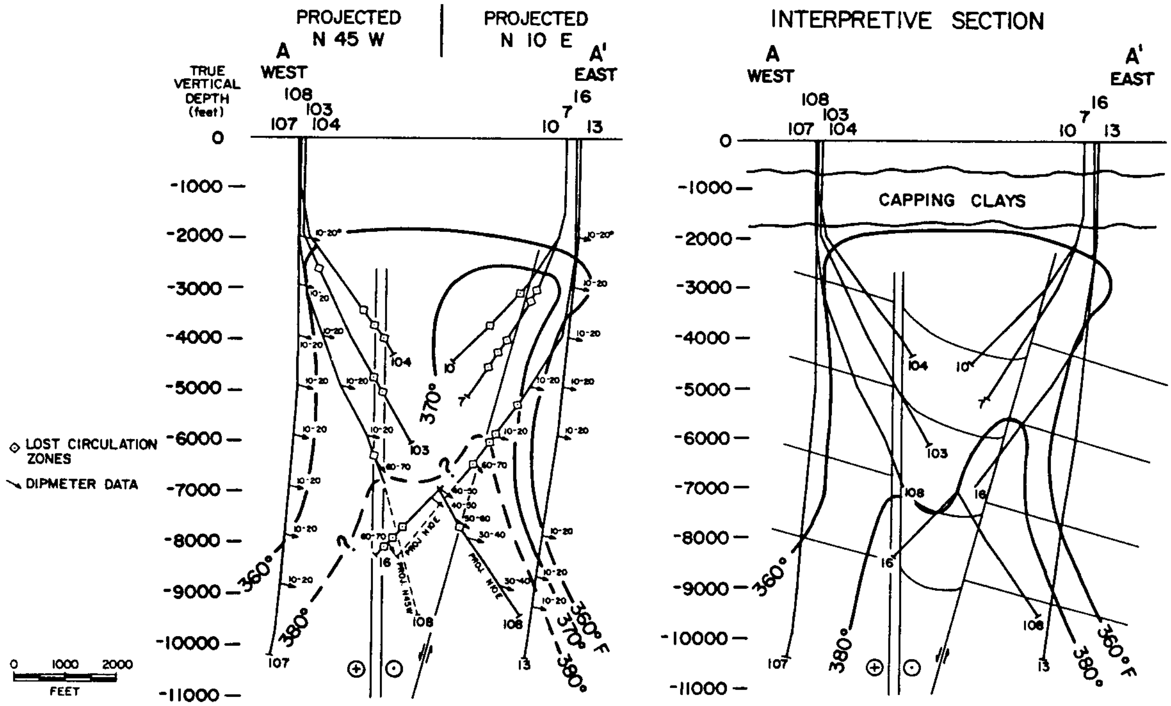

Figure 4. Cross section A-A'. Production wells, temperatures, structure, and lost circulation zones.

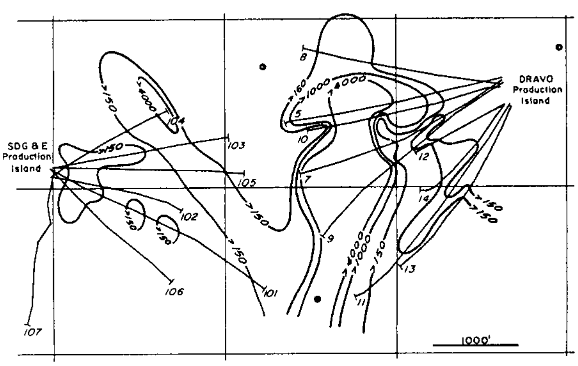

Figure 5. Mud losses (barrels/day) during drilling in Zones I and II.

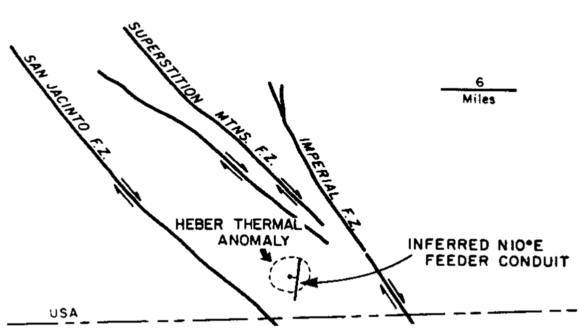

Figure 6. Fault trends in the Heber region showing N10°E feeder conduit in relation to srike-slip structures.

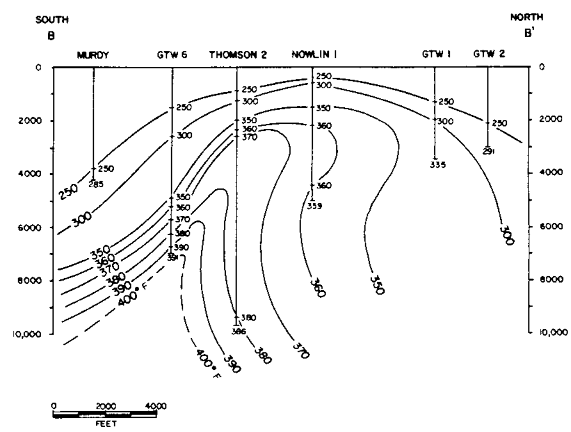

Figure 7. Temperature cross section B-B'.

illustrates the deflection of the rising plume from south to north by groundwater movement. It is also clear from this section that the source of the thermal waters is south of current development near the GTW 6. The shallow matrix reservoir currently under production is at the northern end of the plume. The collapse of the isotherms at the top of the plume is the result of the capping clays sealing in the thermal waters. The strong control of the fracture permeability in the indurated sediments below 5500' is seen in temperature cross section B-B' (Figure 8). The plume is quite narrow east to west and most likely controlled by a narrow structure of high permeability.

The range of Kh (permeability-thickness) values calculated from well test data is indicative of the different sources of permeability in the Heber reservoir. Values in Zone I (2000'-4000', Figure 9) range from 40-80,000 md-ft in the sedimentary reservoir to 120-140,000 md-ft in the strike slip fault to over 200,000 md-ft in the normal fault. The values in Zone II (4000'-6000', Figure 10) are generally lower, reflecting the increasing induration of the sedimentary section.

The sources of permeability are also clearly seen in spinner surveys taken while the wells are producing. The production from the matrix permeability of the sedimentary section is evenly distributed over the entire open interval (Figure 11). Production from fractures comes in very short intervals (Figure 12). The interplay between matrix and fracture permeability explains the wide range of Kh's seen in the well testing.

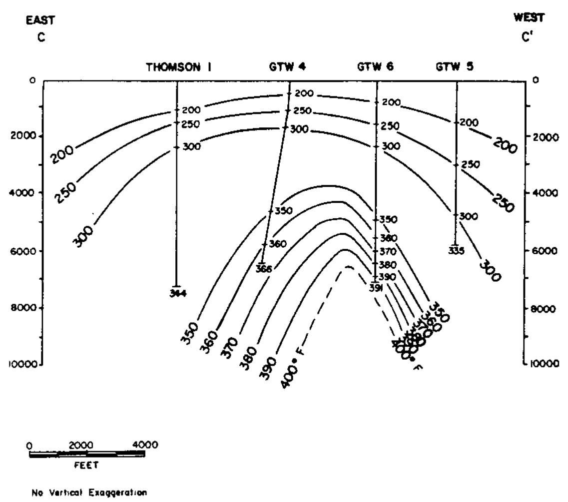

Figure 8. Temperature cross section C-C'.

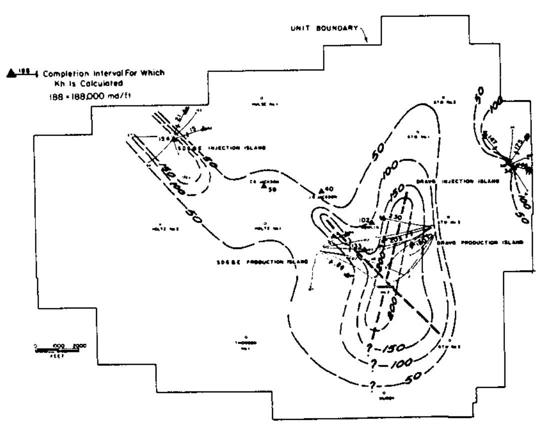

Figure 9. Zone I Kh (1000's millidarci-feet).

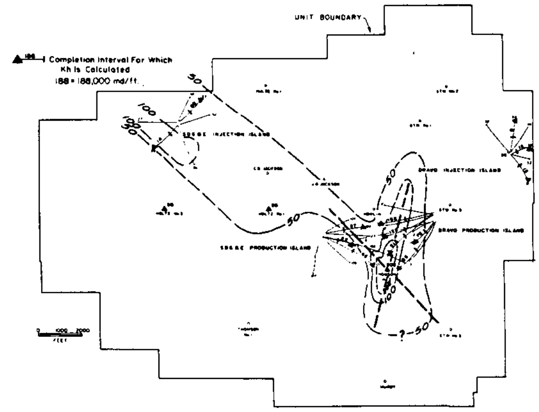

Figure 10. Zone II Kh (1000's millidarci-feet).

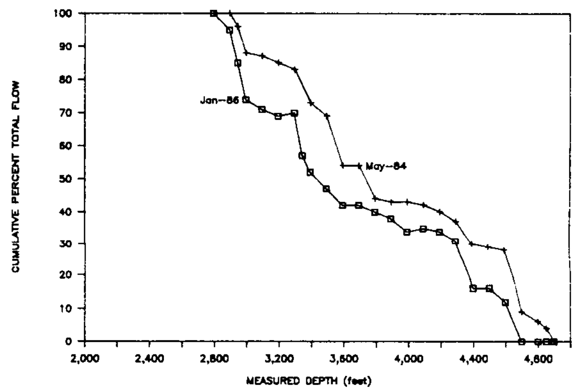

Figure 11. Production spinner surveys from well with sedimentary matrix permeability.

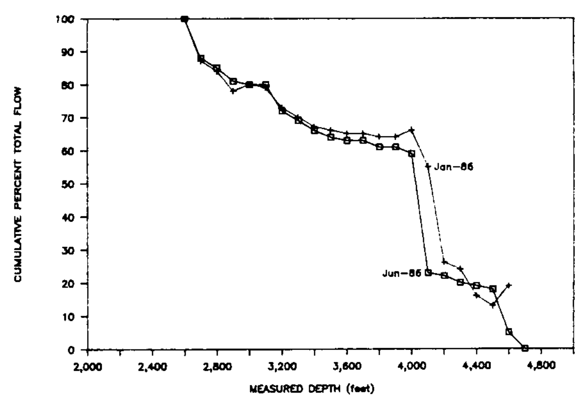

Figure 12. Production spinner surveys from well with fracture permeability.

PRODUCTION CHARACTERISTICS

The productivity index of the wells is closely related to the Kh as calculated from well testing (Figure 13). The most productive wells are completed in the shallow matrix reservoir but are also connected to the fracture system.

The reservoir pressure and production from the wells show a very sharp decline that rapidly stabilizes when the field is brought under full production (Figure 14). The pressure drop created by 50 MW of production is on the order of 80 psi at the observation wells near the center of production. The initial startups of the Dravo and SDGE plants at Heber were staggered and the effect of each plant on the reservoir pressure is clearly seen. The rapid stabilization of pressures indicates the reservoir is very permeable and is strongly supported by the regional aquifer.

A reservoir model was constructed to help predict the pressure behavior of the field and to assess the impact of further development on current production capacity. The permeability model presented in the first section of this paper served as the base of the model. The effect of the regional aquifer support was simulated by using constant pressure boundaries at the edge of the model.

The match to historical data is shown on Figure 14. There is excellent agreement with the data collected. The model predicts very little pressure decline (0-less than 5%) overtime. Additional production will cause an initial pressure drop of similar magnitude to that seen with the present production and pressures will quickly stabilize to the slow decline rate according to model results.

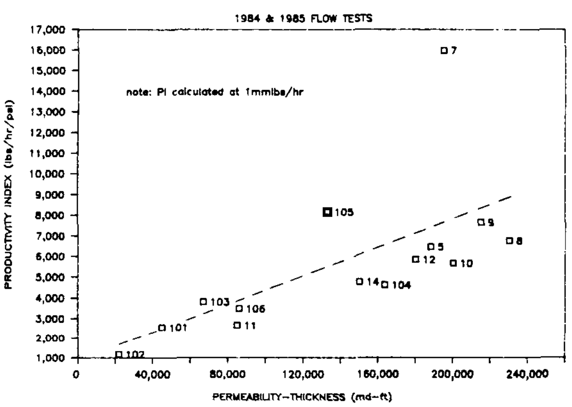

Figure 13. Kh vs productivity.

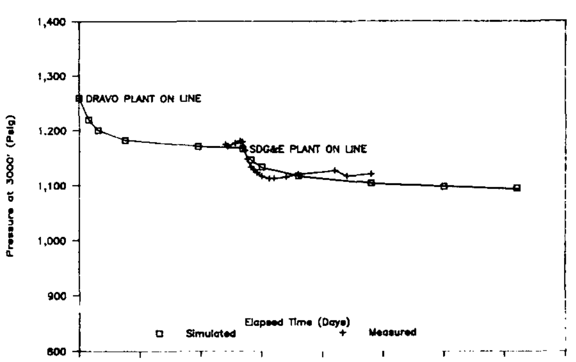

Figure 14. Reservoir pressure at 3000 feet.

CONCLUSIONS

The movement of thermal fluids in the Heber reservoir is controlled by matrix permeability in the shallow sedimentary zone from 1800'-5500' and fracture permeability along NW striking strike-slip faults and NE striking normal faults in indurated sediments below 5500'. Wells produce from both zones giving a range of Kh values from 40,000-200,000 md-ft. Pressures decline steeply under initial production but stabilize rapidly due to regional aquifer support. Decline rates are very low (0-less than 5%).

There is significant opportunity for additional development in the Heber reservoir. Temperature gradient wells drilled in 1986 show that the deep source of the thermal anomaly is south of current production. Modeling suggests that pressure support is adequate for further production.

ACKNOWLEDGEMENTS

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