A STUDY OF THE CERRO PRIETO GEOTHERMAL RESERVOIR

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ABSTRACT

This report describes a simulation study of the Cerro Prieto Geothermal field. A summary of the most important features of the field is presented. Geological, geophysical and hydrostatic models were constructed and adapted. These are analysed and discussed, to obtain a good concept of the geothermal system. Some simulations were carried out using the SHAFT 79 program on a very simply single-layer model. The results were not satisfactory indicating a more complex, probably multi-layer, model is required.

INTRODUCTION

Model simulation of reservoirs is a basic tool for studying a geothermal system. When it is used, greater knowledge of the system can be obtained, thus helping to answer many questions as well as predicting the future reservoir behaviour. This means that an adequate plan for the optimal exploitation of the system can be achieved. The simulation work requires numerical analysis to solve the complex equations of mass and energy transfer. However, at the present time numerical models are available which have been developed for use with computers.

To create a good simulation a large number of parameters must be taken into account, therefore, help is required from scientists such as geologists, geophysicists, geochemists, hydrologists, etc. A preliminary model can be created for a system, based on an initial stage of exploration. This model can then be calibrated with the new wells drilled, the production history and later studies. This work shows a simulation example based on the Cerro Prieto geothermal field, and even though there was not enough time, the author tries to cover the main points.

Firstly, the more important features of the reservoir were summarized, based on various scientific studies carried out in the area. These features and their interpretations were used to create geological geophysical and hydrostatic models, which are compared and discussed to obtain a conceptual model which can be used for the simulation study.

A numerical model was not created to carry out the simulation; instead, the Shaft 79 program developed at Lawrence Berkeley Laboratory was used. The complicated model obtained in this work was not used in the numerical simulation. Instead, a simple model of a uniform layer was adapted to the field characteristics. The simulation work was based on the production enthalpy and drawdown pressure, which have been measured in the more exploited zone of the geothermal field from 1973-78. The results obtained were not successful; they indicate that a fairly good simulation can be obtained only if the real parameters are based on the conceptual model. Any simplified model must be a representative model of the geothermal system.

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I - DATA REVIEW AND INTERPRETATIONS

General Background

The Cerro Prieto geothermal field is situated nearly 30 km southeast of Mexicali City, Baja California. The region is a plain on the Colorado River delta, with the Cerro Prieto volcano prominance standing out.

Geological evidence indicates that the age of the Cerro Prieto volcano is approximately 110,000 years B.P. (De Boer (1979)), and the age of the geothermal system, defined by some authors as a young system, is between 50 and 10,000 years (Truesdell et al (1978a)).

The first shallow wells were drilled in 1961, but the exploratory deep drilling was not started until 1964. The Comision Federal de Electricidad began generation of electricity in 1973, using two turbogenerators of 37.5 MW each. An average of 15 wells with a production of 730 tonnes/hr of steam (Bermejo M. et al (1978)) were required; six years later the capacity of the plant was increased to 150 MW. At present, 88 wells have been drilled, most of them within an area of about 22 Km^2. In order to develop a conceptual model of the reservoir a review of data on tectonics, geology, geophysics, geochemistry, hydrology and well completion was undertaken. Details of this review are contained in Esquer (1981).

II - MODELLING

Geological Model

The geological model (Fig. 1) was adapted from De la Pena et al (1979) and Abril G. and Noble (1978). On the model, only the boundary between the consolidated and unconsolidated sediments (A/B) is shown.

For the purposes of this work, the reservoir is considered to be a homogeneous porous rock, since the production zone is not a uniform layer (Lyons and Van de Kamp (1979)).

The basement depth, due to the lack of information, at least on the western part, was adapted form the resistivity model.

Some of the faults which have been inferred by different authors are shown on the model.

Geophysical Model

The geophysical model (Fig.2) is taken from Wilt and Goldstein (1979). Even though the line under consideration for this model does not correspond to the line for which the resistivity model was developed, previous analysis showed a fairly good correlation.

Hydrothermal Model

To determine the distribution of temperatures through the reservoir, cross-sections were drawn (a typical example is given in Fig.3) Temperature data from Bermejo M. et al (1979) and Mercada G. (1975) were used.

It was assumed that the temperatures are the water-rock equilibrium temperatures, and that the central part of the field had not been affected by the exploitation.

Model Analysis

The cross-section AA' (Fig.3) like other ones (not shown in this work) show the geothermal zone as a thermal plume of 350°C in its hottest part, which ascends from east to west. This agrees with the other authors previously mentioned.

Another cross-section CC (see Esquer, 1981) which is approximately perpendicular to the previous ones, indicates the width of the thermal plume. It shows a more defined boundary towards the north, near well M-172. In contrast, towards the south, the gradient is more uniform. Most of the cross-sections show a gradual decrease of the plume at the southeast of the field.

In some of the cross-sections, it is evident that there is an upflow of the thermal plume. It is located approximately in an elongated zone heading approximately south-north. This upflow is where the thermal fluids discharge to the upper strata of the reservoir.

Section DD (see Esquer, 1981) shows some of the wells located within this zone, whose isotherms clearly indicate the existence of a discharge zone.

This zone clearly coincides with the location of the Hidalgo fault according to De la Pena et al (1979) and Bermejo M. et al (1979), or with a very fractured zones, as Puente C. and De la Peña (1978) describe it. The exact location of the fault or faults differs according to the different authors. This upflow zone was also compared with the dipolar anomaly proposed by Corwin et al (1978, 1979) and the two are very similar.

An analysis of the production data indicates that most of the wells which are located along this upflow zone showed high enthalpy at the beginning of their exploitation. This was interpreted as the existence of a steam zone (Bermejo M. et al (1979) and Truesdell et al (1978b). This steam could have formed during the ascent of the fluids and it accumulated in the upper strata of this zone, since, as Bermajo M. et al (1979) mention, this steam was extracted during the first years of exploitation.

The horizontal flows shown by the cross-sections advance towards the western part of the field, and some of them become present in the thermal manifestations in that area, where the A/B boundary is less evident (Puente C. and De la Peña (1978)). These thermal manifestations have decreased due to exploitation.

The wells located in the west, southwest and northwest of the field show reverse temperatures, forming convection cells, which indicate the intrusion of colder fluids into the reservoir. The hottest fluids seem to extend up to but not beyond the upflow zone.

The gradual temperature gradient towards the east of the field suggests a large cold front acting over the thermal plume; this cold front could be the waters coming from the Colorado River, as was suggested by Mercado G. (1975).

When the geological model is compared with the hydrothermal model (Fig. 1 and 2), the thermal profiles look like the A/B boundary. This indicates the effect of hydrothermal metamorphism on the sediments, as Elders et al (1978) mention.

Some of the faults are evident on the temperature cross-sections; others, however, located in the eastern part, which have been proposed by the authors, are not apparent. This may require a more detailed analysis.

Figure 2 shows the location of the Cerro Prieto fault according to Abril, G. and Noble (1978). It indicates the boundary of the field, as was suggested by other authors, because this fault could be a conductor for colder fluids coming from the alluvian fans (Mercado G. (1975)) or the recharge indicated by Truesdell et al (1978a)).

The steep slope of the thermal profile between wells M-53 and M-172 suggests the existence of a boundary nearby. This could be a fault, as s stated by De le Peña et al (1979) and Bermejo M. et al (1979), who believe that the Hidalgo fault passes about 0.5 km north of well M-172.

When the geophysical model is compared with the hydrostatic model, the resistive body of 4 ohm-m seems to be the thermal plume at its hottest part (350°C) but it is not similar in the east, where the thermal plume is within the resistive body of 1.5 ohm-m. This body of 1.5 ohm-m seems to be a body of water, the temperatures of which are 250°C and less.

The thermal plume is deeper towards the southeast, perhaps indicating the gradual upward movement of the hot fluids coming from that direction, which is in accord with a magnetic anomaly at the southeast of well NL 1, stated by Fonseca and Razo (1979).

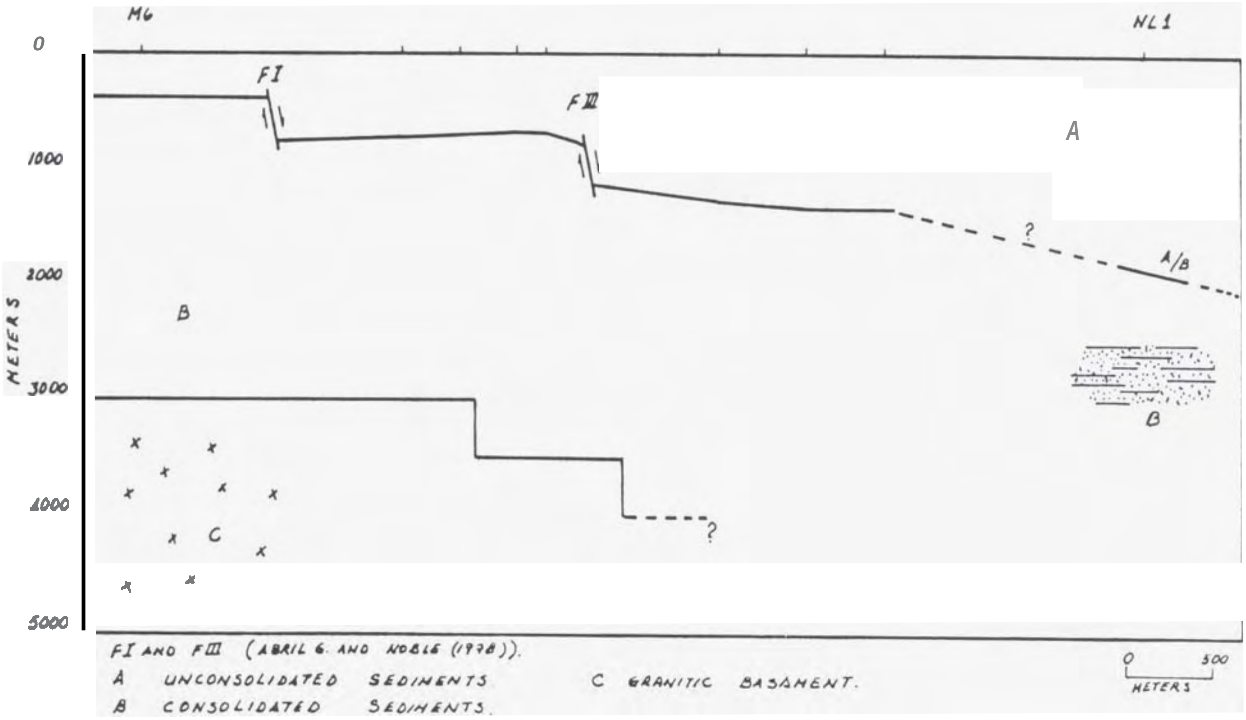

FIGURE 1 : Geological model. (Adapted from Puentec and De la Peña(1978) and Abril, G. and Noble (1978).

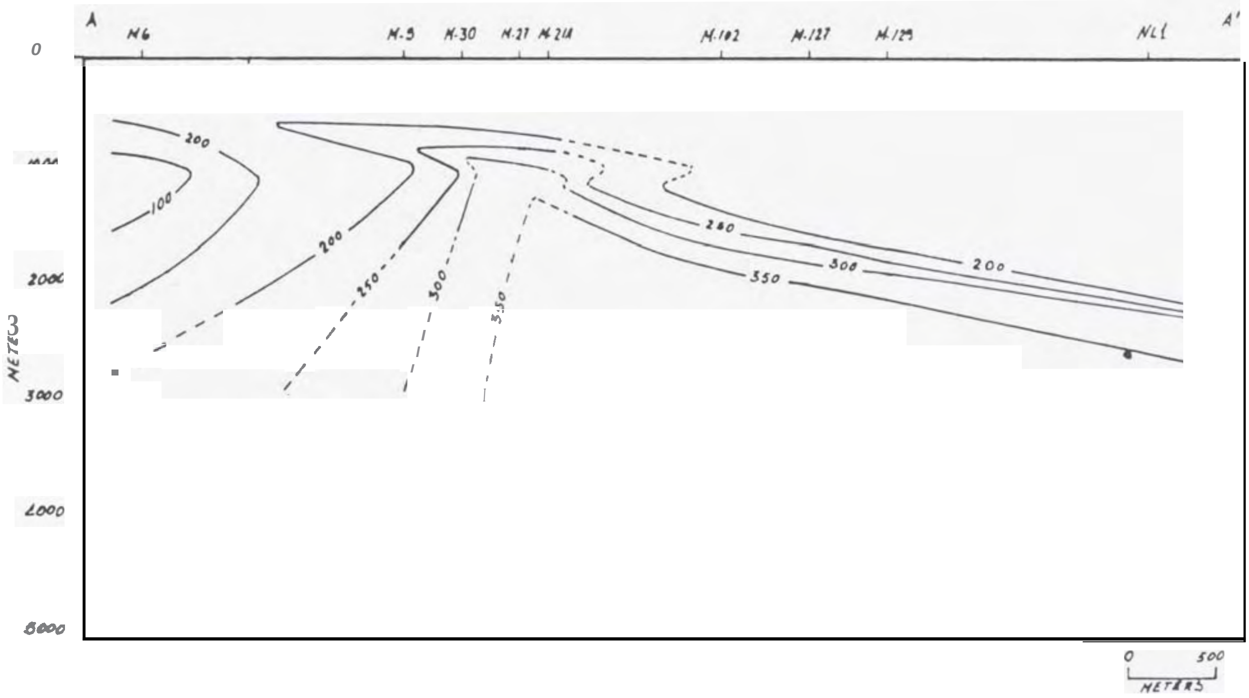

FIGURE 2 : Hydrothermal model, distribution of temperatures (°C) along the AA' cross section.

Summary

CONCLUSIONS

1. A fairly good concept of the geothermal system has been obtained. This can be adapted for simulation work.
2. The upflow zone seems to be dominated by several faults instead of one. It corresponds to a very fractured zone as Puente C. and De la Peña (1978) stated.
3. The geological, geophysical and hydrostatic models were placed in an east-west position because of the fluid movement in this direction.
4. At present, the temperature patterns of the exploited zone have been affected due to continuous exploitation. The scaling deposition which is found mainly in the wells surrounding the shallow zone, the geochemical evidence and downhole measurements suggest the intrusion of colder fluids, which must have affected the fluid and rock properties in that part of the reservoir.

III - SIMULATION

Previous Work

Earlier work reveals the attempts to construct a suitable model for the Cerro Prieto geothermal field. From these earlier studies the author only has information of advances until 1979.

Lippman et al (1978) develop numerical models to compare the effects using isothermal data in geothermal systems (not isothermal) applying these to a simple model of Cerro Prieto. They show the effects of the upper and lower recharges upon the reservoir temperature.

Lippman and Goyal (1979) carried out numerical simulations on a geological model, establishing the recharge and discharge conditions of the field before exploitation.

Liguori (1979) shows a mathematical model calibrated under production characteristics through the exploitation time, and he simulates the evolution of the unexploited area.

Molinar C. et al (1979), using a confined aquifer simplified model, predict the future conditions under 1500 MW generation.

The Model

As a first attempt a simple square model was chosen. It was divided into 9 blocks, each one of 1.6 km x 1.6 km x 200 m in size. The model was adapted to the drilled area, and most of the production wells were taken into the central block.

Several simulations were carried out using this simple model (see Esquer, 1981, for details) but none were successful in producing a good match of pressure and enthalpy history.

CONCLUSIONS

1. None of the simulations carried out can be considered successful.
2. The enthalpy and pressure matches could have been obtained, but even then this project could not have been considered successful, because the conditions considered as initial conditions of the reservoir would not have corresponded to the real conditions.
3. The model chosen for simulation was not the most appropriate one for doing this work, which requires at least three layers. The reservoir should have been considered as a central block divided into small blocks, because the model considered was too big to be considered as isothermal and with isotropic permeability.
4. This simulation work shows why the simulation must be based on the real characteristics of the system. More time would be required, but the results should be more successful.

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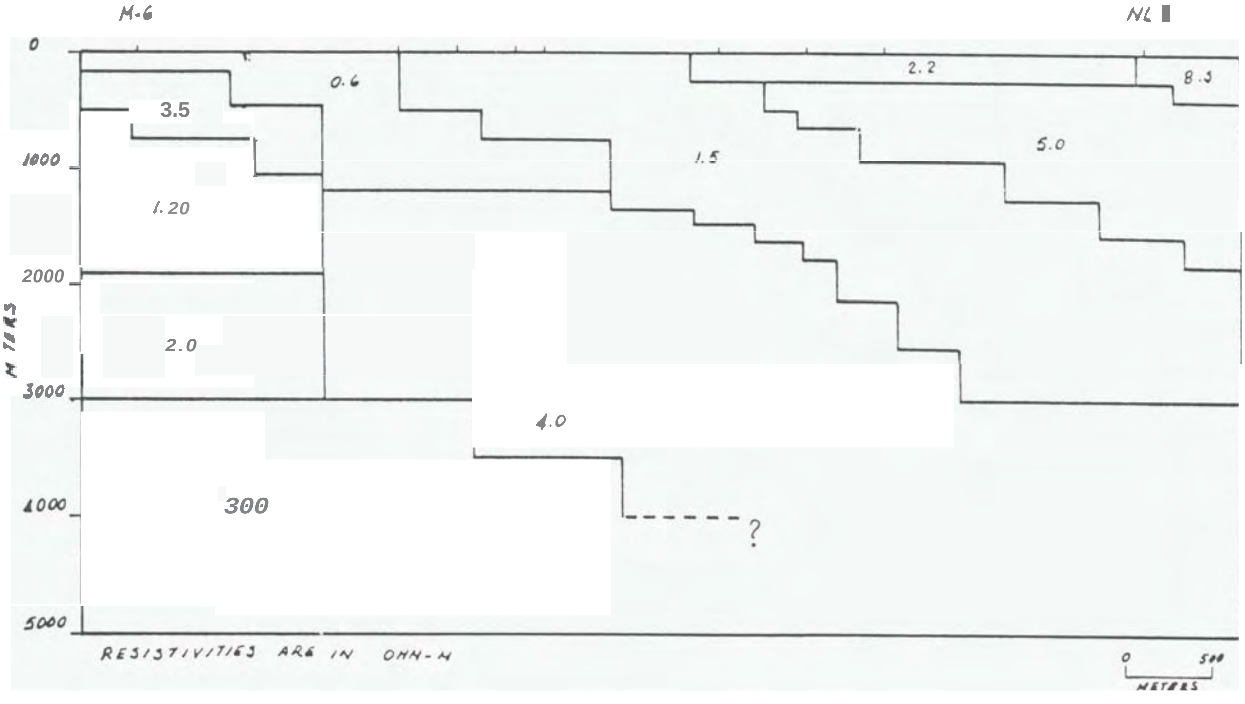

FIGURE 3: Geophysical model. (Adapted from Wilt and Goldstein (1979)).