DEEP WELL GEOTHERMAL DEVELOPMENT IN CERRO PRIETO, B. C. MEXICO

By Jaime Mario E. Vaca Serrano and Héctor Gutiérrez Puente
Comisión Federal de Electricidad

ABSTRACT

The object of this paper is to describe the project of drilling an exploratory deep well down to 6000 m, in the Cerro Prieto geothermal field, in order to re-evaluate the estimated reserves of the field and to up-date the conceptual geological model.This model relates the heat source with the hypabyssal rocks which give origin to the Nuevo León magnetic anomaly in Cerro Prieto, in the east zone of the field, which would help to define the feasibility of a deep geothermal development.

INTRODUCTION

The Cerro Prieto geothermal field is located in the alluvial plain of the Mexicali Valley, 30 km southwest of the City of Mexicali, in the Northeastern portion of Baja California State (Fig. 1).

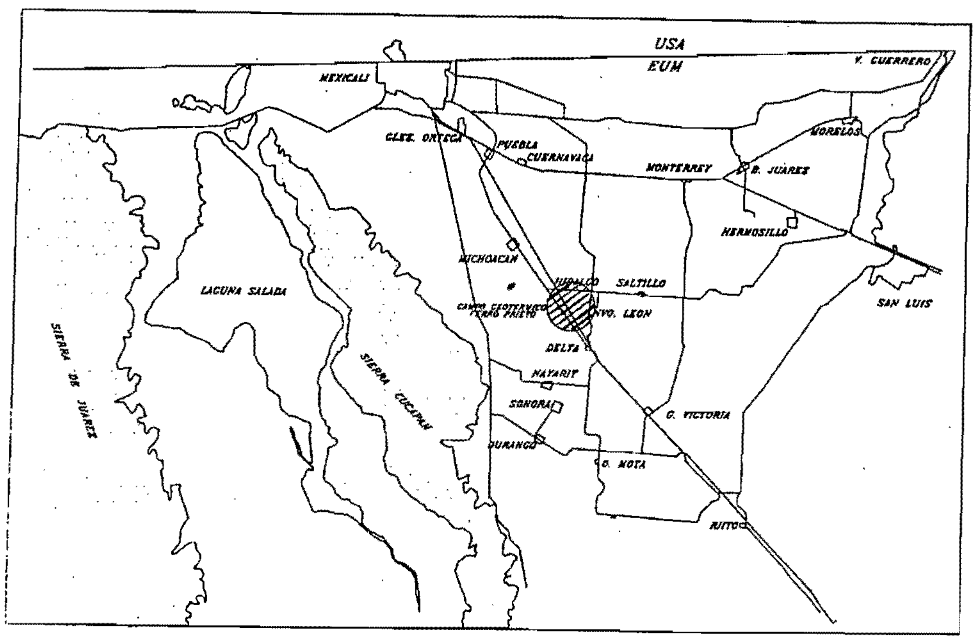

fig. 1 Location of Cerro Prieto geothermal field

The Mexicali Valley, along with the Salton Through, make up one of the geologic provinces with the largest geothermal resources in the world. Several studies have been performed in this province, aimed to determine its geothermal potential, having obtained as a result the discovery and development of the Cerro Prieto Geothermal Field.

In order to enlarge the knowledge of the geothermal system used to generate electric power, Comisión Federal de Electricidad (CFE) is planning to drill a deep well. Drilling of this well would allow to re-evaluate the estimated reserves of the resource and update the conceptual geological model that relates the heat source whith the hypabyssal rocks and that give rise to the Nuevo León magnetic anomaly, in the Eastern part of the geothermal field.

GEOLOGICAL SETTING

Geologically, the province of the Mexicali Valley is located within the transform system of the San Andrés fault, which is regionally characterized by the Cerro Prieto spreading center (Elders et al., 1972, and Goldstein *et al.*, 1982), formed by the Imperial and the Cerro Prieto faults.

The volcanic structure of Cerro Prieto, is of rhyodacitic composition and the age of its rocks, according to Boer (1979), is 110,000 years, since then, volcanic activity continued on and off until 10,000 years ago.

Five main lithological units have been very well defined for the Cerro Prieto geothermal field: granitic basement, gray shale, brown shale, mudstone, and clastic unconsolidated sediments (Fig. 2). Also the presence of igneous hypabyssal rocks is known, which have been identified in 9 wells towards the NE of geothermal field (Lippmman, 1987). The rocks are mainly basalts and andesites.

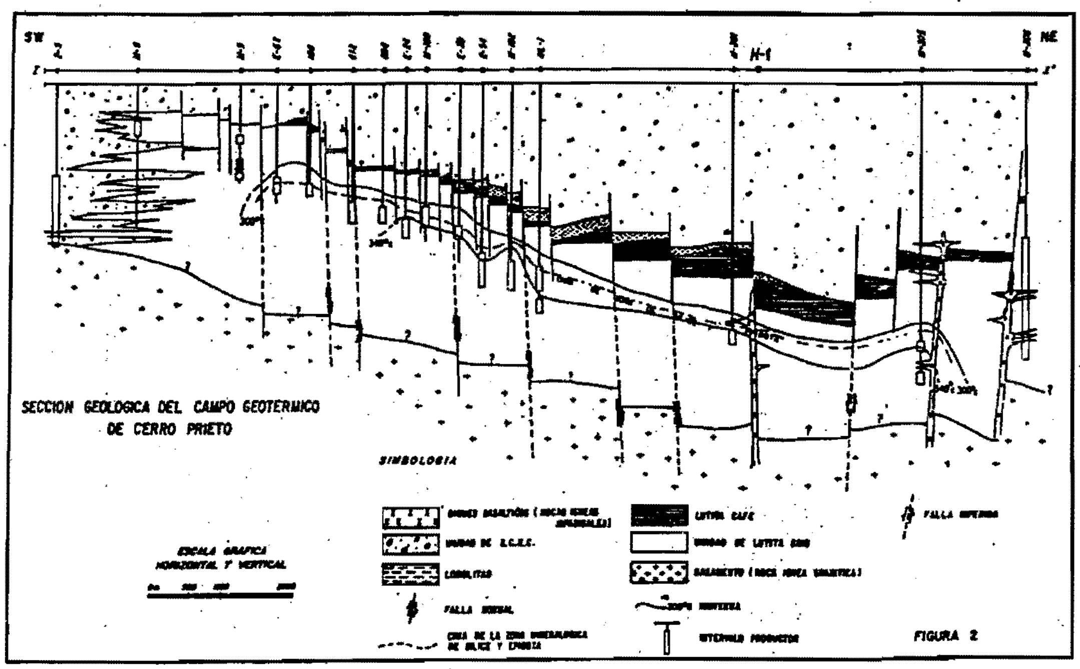

Fig. 2 Geological section of the geothermal field

The granitic basement has been reached by 4 wells and it has been interpreted that these rocks gradually deepen towards the East (Fig. 3), reaching estimated dephts, based on gravimetry, magnetometry and reflection seismology, of 6000 m (Fonseca and Razo, 1979).

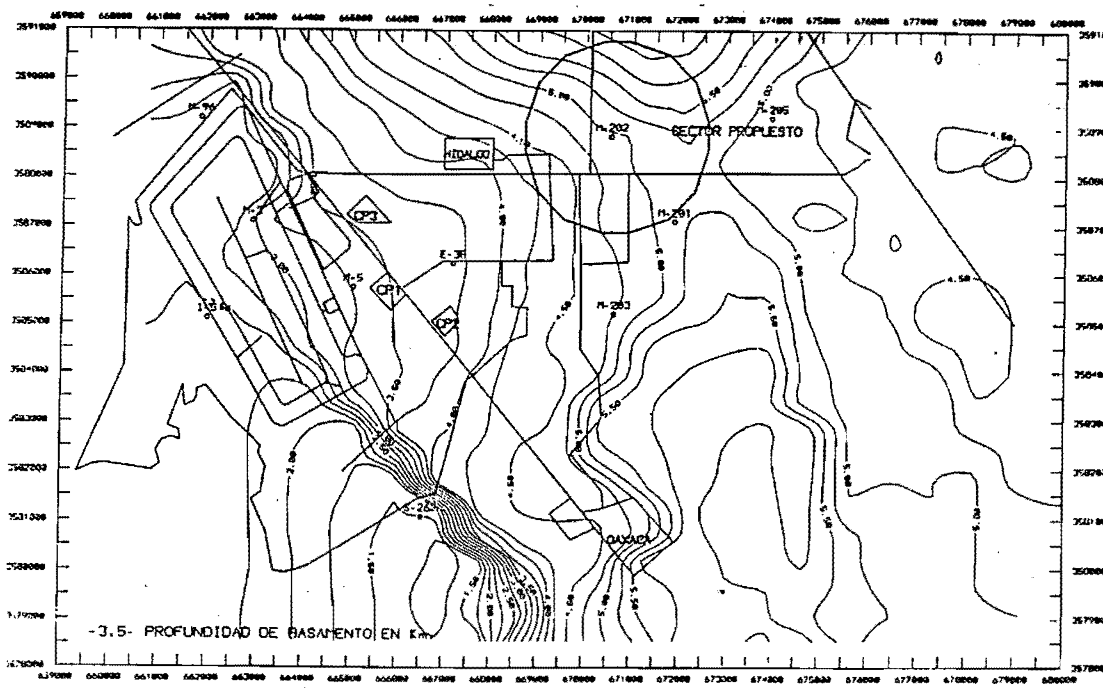

Fig. 3 Granitic basement configuration

The gray shale unit is constituted by an intercalation with lenticular sandstones. The thickness of the gray shale in the field is 2147 m, therefore, with the drilling of the deep well, its total thickness towards the East portion will be determined. Partially overlaying the former sedimentary complex, there are brown shales whit a maximum thickness of 500 m. On the top of those units there are erratically distributed mudstones that reach a thickness of 500 m.

Because of the fact that the age and depositional environment of the sedimentary units at east of the field are unknown, some stratigraphic studies will be perfomed in the deep well that CFE will drill.

According to the spreading center model proposed by Elders (1972) (Fig. 4) for Cerro Prieto, a tectonic basin filled with sediments located on acid intrusive rocks (granites) should be expected. The basin must be intruded by basaltic magma, causing methamorphism of the sediments, and in a later stage, by tholeitic magmas coming from the mantle that assimilate and melt the granitic basement. This, along whit the rise of geothermal fluids, produces shallow green schists facies on the consolidated and unconsolidated sediments.

With the drilling of such deep well, igneous rocks will be identified and classified. This will lead to a better knowledge of the magmatic evolution in the subsurface, in order to update the geological model of Cerro Prieto.

Lippmman and Bodvarsson (1983), suggest that in its natural state, the field is recharged from the east by hot (about 355°C) deep water and from both the east and the west by colder (between 50° and 150°C) waters from shallower aquifers.

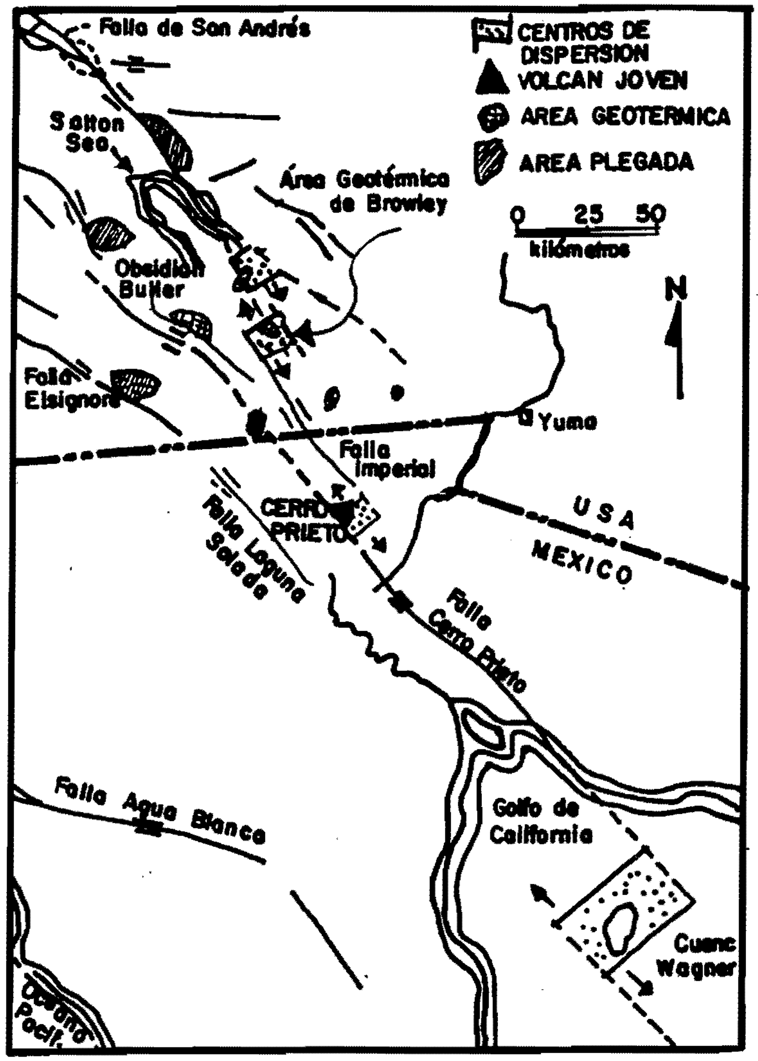

Fig. 4 Transform fault and spreading center model proposed by Elders

GEOPHYSICAL SETTING

Geological interpretation of the subsurface has demanded the carrying on of geophysical studies, like reflection and refraction seismology, microseismicity, gravimetry, magnetometry, direct current electric methods, self-potential, magnetotelluric, thermometry, and geophysical logs in wells.

Seismological and gravimetric studies have lead to infer the presence of a crystalline basement structure with NW-SE trended faulted blocks, limited to the west by a graben and to the east by a deepening of the basement. Later seismologic studies found an important series of earthquakes in the proximities of Cerro Prieto and Imperial faults that, along with the recent tectonic activity, allowed to suggest the existence of a transform fault system and the presence of a spreading center in Cerro Prieto (Lomnitz *et al.*, 1970).

Magnetic anomalies map showed characteristics similar to those in the Bouguer anomalies plane, that were associated tc the results of the crystalline basement whose magnetic susceptibility is bigger than that of the sedimentary filling. Figure 5 shows the positive magnetic anomaly and the interpretations of the body source that is located to the east of the reservoir. This, along with hypabyssal rocks of well NL-1, allowed the interpretation of a magnetic body associated to the heat source of the hydrothermal system (Elders *et al.*, 1984; Lippmman *et al.*, 1987).

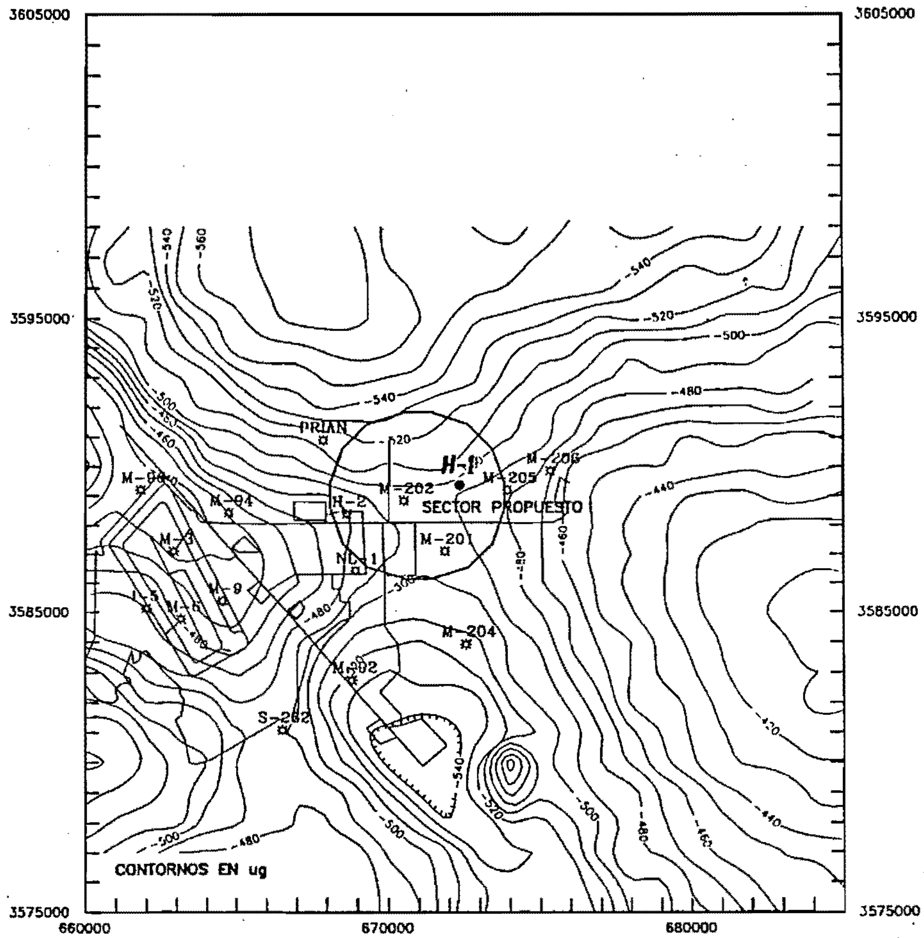

Fig. 5 Bouguer Anomalies map

Goldstein *et al.* (1984) estimated that the roof of the magmatic source is located 3.5 km below the surface, and that the melt zone could be located between 9 and 10 km depth, as it is determined from observations an from an analysis of Curie's isotherm (Lippmman, 1983). Recent analysis of magnetic data confirm the existence of a magnetic body, but its peak is inferred at 6,000 m depth, and its dimensions are greater.

From the interpretation of seismic lines of reflection (Romero, 1986) within the field and in the Mexicali Valley, two transform faults with a dextral movement (to the east of the Cerro Prieto fault and to the west of the Imperial fault), conform a graben. This graben has a NW-SE trend, its shallowest part to the NW of the area, and a trend to deepen towards the SE.

DRILLING PROPOSAL

Location: To the east of well M-202 and northeast of well M-201 (Fig. 3).

Name: H-1.

Depth: 6,000 m approximately.

Completion: 6" diameter, open hole.

Objectives of Deep Well

- To determine the real thickness of the Cerro Prieto geothermal reservoir.

- To improve the geological model.

- To re-evaluate the potential of the reservoir and to establish new exploitation alternatives in the Eastern portion.

Drilled wells background

Deep exploratory wells have been drilled where the proposed deep well H-1 will be drilled. The deepest one is well M-205, at 4,389 m depth, having gotten lithological information and a measured temperature of 340°C (Table 1).

TABLE 1. DEEP WELLS DRILLED IN THE AREA OF WELL H-1

Casing depths (m)

Well	Total depth	Hole ϕ	20"	13 3/8"	9 5/8"	7"	4 1/2"	Observations
M-201	3817	6"	57	1041	2392	2340-3609	3565- 3810	
M-202	3987	6"	103	1000	2440	2389-3488	3435-3986	
M-205	4389	6"	53	682	2478	2423-3764	3733-4388	
M-206	4024	8 1/2"	94	681	2233	---	---	Completed in 8 1/2" open hole.

Drilling Activities Program

First stage

It will be drilled a 26" diameter hole to a depth of 160 m using mud as drilling fluid, sealing the permeable zones. 20" diameter casing will be installed and cemented from 150 m depth to surface.

Second stage

It will be drilled a 17 1/2" diameter hole, from 160 to 2450 m depth, using mud as drilling fluid, sealing all the permeable zones. 13 3/8" diameter casing will be intalled and cemented from 2,440 m depth to surface

Third stage

It will be drilled a 12 1/4" diameter hole, from 2450 to 3700 m depth, using mud as drilling fluid, sealing all the permeable zones, in order to install and to cement 9 5/8" diameter casing from 3,700 m depth to surface.

Fourth stage

It will be drilled a 8 1/2" diameter hole, from 3700 to 5150 m depth, using mud as drilling fluid, sealing all the permeable zones, once the geothermal characteristics have been known and evaluated. In order to install and cement the 7" diameter liner from 3600 to 5,150 m depth.

Fifth stage

It will be drilled a 5 7/8" or 6" diameter hole, using mud as drilling fluid from 5150 to 6000 m depth as planned. The well will be completed in open hole. During drilling all the potential geothermal zones will be evaluated and then sealed in order to continue the drilling to reach the total depth.

Associated Activities During the Deep Well Drilling

- The stratigraphic and mineralogical columns of the sedimentary sequence will be determinated.

- The thickness, ages and depositional environment of the sedimentary complex will be determinated.

- The depth of the basement, its classification and rock geochemical composition will be defined.

- Hypabyssal rocks will be identified and classified.

- Relation between the hypabyssal products and/or basement rocks, and the Nuevo León magnetic anomaly will be investigated.

- Chemical and isothopic characterization of geothermal fluids will be done.

- Pressure, temperature and geophysical logs will be performed.

- Rock and core sampling will be done.

- Production tests at depths below 4,000 m will be run.

- Pressure-temperature and spinner loggings will be run during production tests.

PROBABLE LITHOLOGICAL CONDITIONS OF DEEP WELL H-1

Temperature distribution

Considering the static formation temperatures of well M-202 and of those wells near it, the temperatures that could be measured in well H-1 were estimated. At a depth of 2,700 m it is expected to find a temperature of 200°C. At 3,700 m depth, 340°C, reaching 350°C before 4,500 m. It is expected that reaching 6,000 m depth, temperature will be near 360°C.

Estimated Lithological and Mineralogical Conditions

According to configurations of the top of the lithogical units in the referred area, it is expected to drill the following units:

DEPTH (m)	LITHOLOGICAL UNIT
1,800	Base of unconsolidated clastic sediments.
2,000	Top of mudstones.
2,200	Top of brown shale.
2,400	Top of gray shale.
3,700	Top of the silica-epidote mineralogical zone.
5,100	Top of the granitic basement.

Proposed Completion

Completion of the well, excepting 20" diameter casing, will be determined according to lithological contacts, so it is estimated to be as follows:

DEPTH (m)	CASING (diameter)
0 - 150	20"
0 - 2,440	13 3/8"
0 - 3,700	9 5/8"
3,600 - 5,150	7"
5,150 - 6,000	6" (open hole)

Well Tests During Well Drilling

Stabilized temperature determination

Temperature logs will be run at the following depths: 4,000, 4,500, 5,000, 5,500 and 6,000 m, with 4, 8, 12, 16 and 20 hours of repose time, in order to determine the stabilized formation temperature.

Test description

In order to run this test, the well must be prepared with the lightest possible mud, which will must have a hardening time no longer than 24 hours. High temperature Kuster equipment will be utilized. CFE personnel will be in charged of measurements.

Transitory pressure tests

Injection-recovering test.

Transitory pressure tests are planned to be made at a depth of 4,500 m and 5,500 m, with the following purposes:

a) To identify potential feeding areas.

b) To determine the average permeability of the zone, to know if the well could be used for production or for injection.

c) To determine the injection well index.

Temperature, pressure and flow loggings (spinner) must be made during these tests. Duration of this test will be 48 hours.

Production tests

If an interesting zone would be found and if it would be decided to make the well flow in order to evaluate it, having installed the rig, the induction should be made using nitrogen injection with continuos equipment, to reduce the stimulation time. The estimated time for this test will be three days.

CONCLUSIONS

Drilling of the deep well will allow to confirm several hypothesis and interpretations on deep subsuface conditions in Cerro Prieto. Among those: to define the actual density of the geothermal deposit; improve the geological model of the field; to re-evaluate the potential deposit, in order to define exploitation alternatives of the field's deep portion. Also, definition of the necessary activities for drilling such deep well, will allow resolution of related problems as: very high temperatures, drilling rates, circulation losses, drilling tools or drill pipes failures, etc.