HEAT SOURCE AND GEOTHERMAL GRADIENT OF THE CERRO PRIETO FIELD

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ABSTRACT

The geothermal gradient at Cerro Prieto obtained from data on temperature measurements in deep wells on standby condition is approximately 15°C per 100 m of depth. Comparing this with the normal geothermal gradient, the area possesses a gradient five times normal, which is caused by melted rock or lava intrusions that probably exist at very shallow depths of about 6 to 8 km.

INTRODUCTION

The Cerro Prieto geothermal field is located 30 km southeast of the city of Mexicali, Baja California (Figure 1). Currently 400 MW are generated by C.P.I and C.P.II central power stations, which utilize the steam extracted from 55 wells of 1200 to 3200 m depth. Cerro Prieto is characterized by an extensive geothermal anomaly, from which the reservoir presently under exploitation originated.

The normal geothermal gradient of the earth is about 3°C per 100 m; e.g., at depths of 1000 m, one would measure a 30°C temperature rise in almost every part of the world. In Cerro Prieto, at depths of 1000 m the increase is 150°C as a mean value. The geothermal anomaly of Cerro Prieto dates from thousands or hundreds of thousands of years. It originates in the constant movement of the Pacific terrestrial plate towards the northwest, which provokes crustal failures from the Gulf of California, Mexico, north to the city of San Francisco, California, USA. From the geothermal point of view such failures are nothing more than fissures through which magma ascends and becomes a heat source resulting in a geothermal anomaly (Figure 2).

Cerro Prieto has a volcano after which the field was named. It is a hill of black lava overflow resulting from the migration of magma to the surface. There have also been other magma migrations which did not reach the surface; in these, the molten lava remained trapped at relatively shallow depths of less than 10 km (Figure 2).

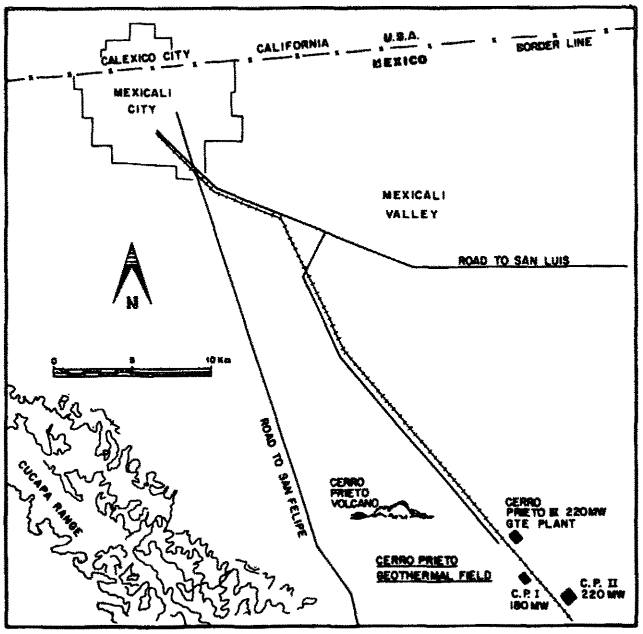

Figure 1. Location of Cerro Prieto geothermal field

During the process of cooling and crystallizing, these magma masses have liberated enormous quantities of energy and hot gases, which have been accumulating in the subterranean aquifers below the Mexicali Valley. Through

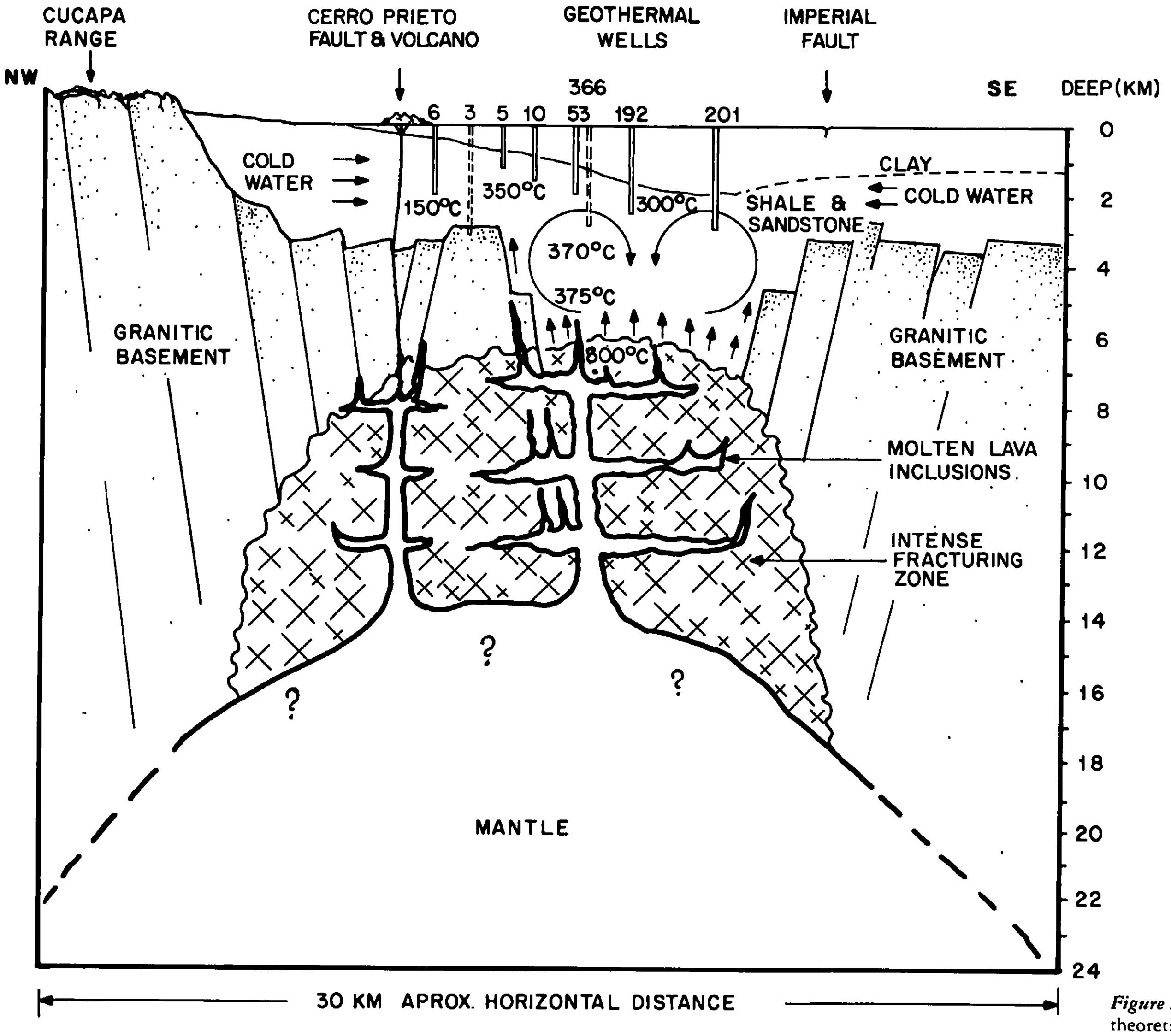

Figure 2. Cerro Prieto theoretical model

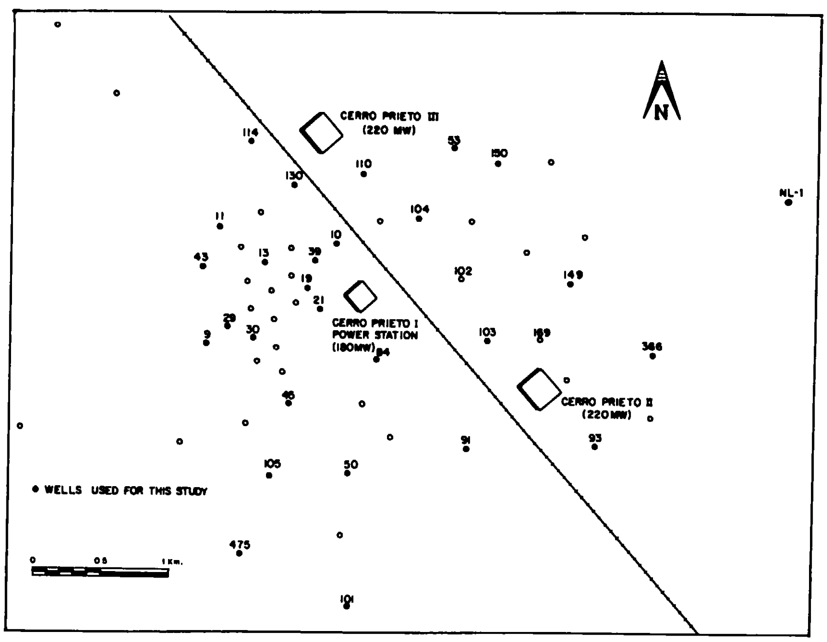

Figure 3. Locations of wells and plants at Cerro Prieto geothermal field

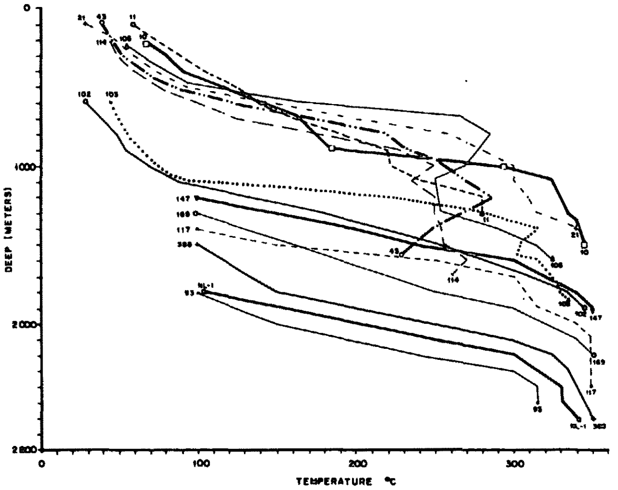

Figure 4. Temperature profiles of some Cerro Prieto wells

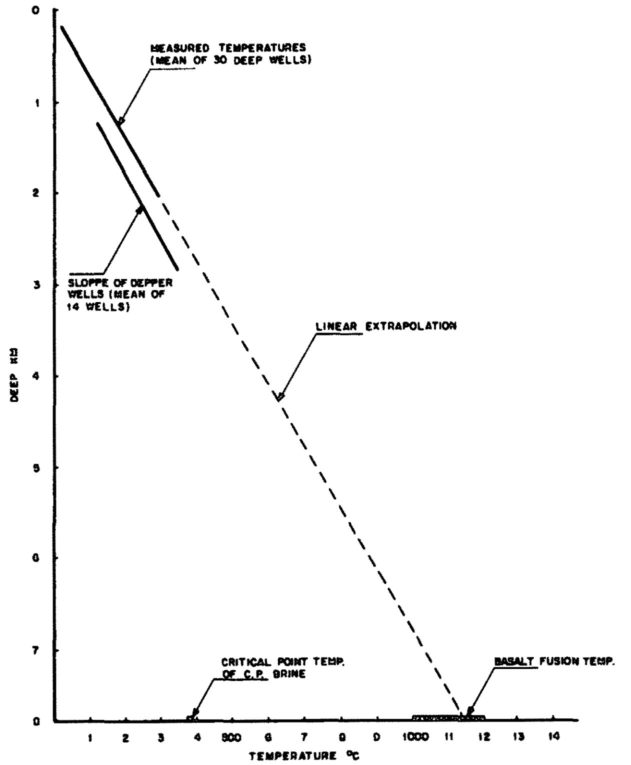

Figure 5. Linear extrapolation of geothermal gradient

convection processes, the temperature in the aquifers has been equalizing and steadily rising. The result has been the formation of the hydrothermal reservoir currently under exploitation, which has an average temperature higher than 340°C. The measurements taken in the reservoir indicate an anomalous geothermal gradient of 15°C per 100 m depth. Details of the area under exploitation and well locations are shown on Figure 3.

CALCULATION OF THE GEOTHERMAL GRADIENT IN CERRO PRIETO

The geothermal gradient at Cerro Prieto is given a

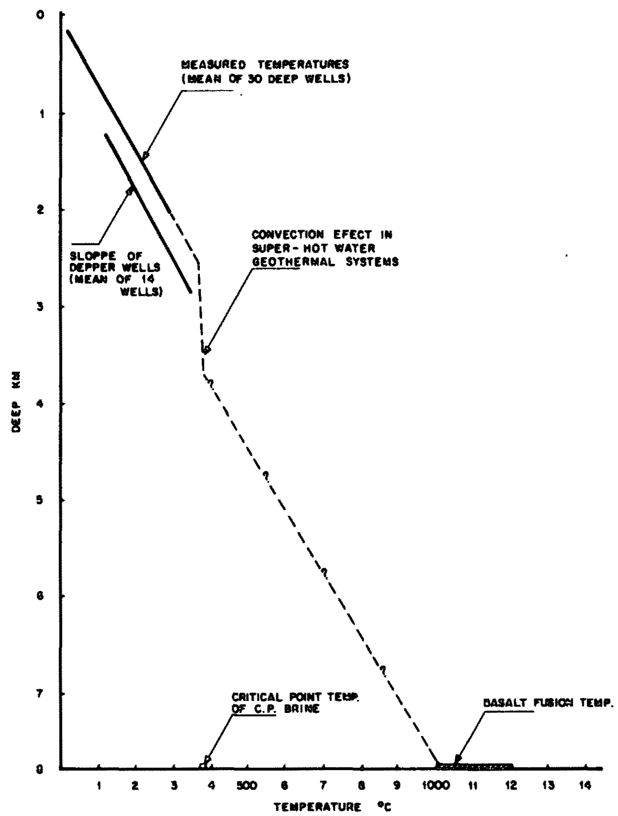

Figure 6. Extrapolated temperatures in convection system

statistical and graphical representation in Figures 4, 5 and 6, using data from temperature measurements (on standby condition) in wells M9, M10, M11, M13, M15, M19, M21, M29, M30, M39, M45, M53, M84, M103, M104, M105, M114, M130, M149, M150, M181 and M473. In Figure 6 the slope for deep wells includes M91, M93, M101, M109, M110, M117, M147, M172, M192, M201, M328, M348, M366 and NL-1 (temperature data taken from Bermejo 1979, 1984, and Castillo and others, 1981).

These wells have been drilled to depths of 1220 to 3200 m. The geothermal gradient at Cerro Prieto is 15°C per each 100 m; since the normal gradient is 3° per each 100 m, the significance of the Cerro Prieto value may be appreciated: this area possesses a gradient 5 times normal.

Extrapolating the mentioned measurements, it is possible to obtain the approximate temperatures at depths greater than those of the wells. Applying a linear extrapolation or considering a convecting model, the values in Table 1 and in Figures 5 and 6 are obtained.

From the temperatures in Figures 5, 6, and 7 and Table 1, the following possibilities exist:

A. In zones of high temperature wells, at greater unexplored depths, there may exist strata of superheated steam caused by possible migration of very high temperature fluids through the fractures connecting the upper strata with conduction zones.

B. At a depth of 6 to 8 km, melted rock should be found.

A'. Production of Dry Steam at 4 km and below. Regarding the first possibility above, temperatures of around

Table 1. Linear and convection extrapolation of temperatures in Cerro Prieto based on the average geothermal gradient in the wells

Depth (km)	Temperature °C (A) Linear*	°C (B) Convecting
1	150	150
2	300	300
3	450	375
4	600	380
5	750	530
6	900	680
7	1050	730
8	1200	980

*Low probability

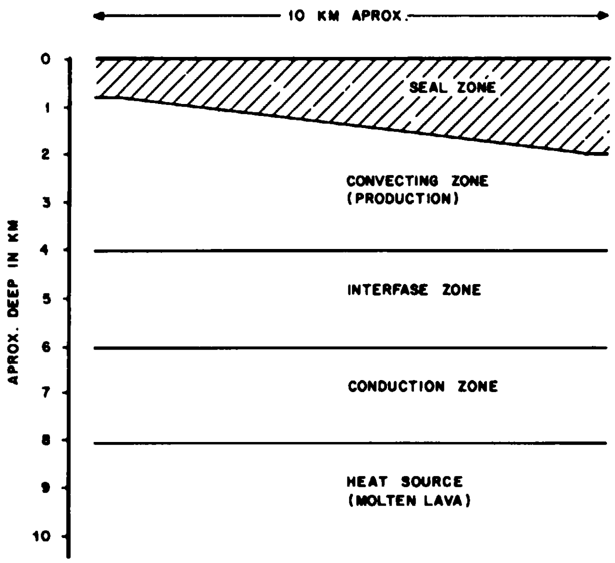

Figure 7. Zone distribution in Cerro Prieto geothermal model

380°C would be found at a depth of 4 km according to the gradient calculations. This value may be compared to the critical temperature of brine extracted from wells. Although this had not been proved because such depths have not been reached in the high temperature zones of the field, there are some indications that such conditions can exist. For example, the mixture extracted from most of the wells is 60 percent water and 40 percent steam, while in wells 21, 21A, 45, 48, 84, 102, E7, which are located in one of the highest temperature zones, the extraction is a high enthalpy geothermal fluid. A mixture of only 20 percent water and 80 percent steam has been obtained. On this basis, it is considered possible to extract dry, superheated steam from greater depths in this and other parts of the field. The extraction of dry steam has the advantages of more efficient exploitation of the geothermal resource and the elimination of problems caused by dissolved solids in the brine.

B'. Melted Rock at Depths of 6 to 8 km. Considering this second possibility, according to the extrapolated geothermal gradients, temperatures of 900 to 1200°C would be encountered at a depth of 6 to 8 km. For example, basalt begins to melt at 1000°C and is completely melted at 1200°C. Thus, it is almost certain that there would be molten lava at these depths (Figures 2, 5 and 6), provided the extrapolated temperatures are correct. This is further supported by studies made during the International Geophysical Year, which indicated that the Mexicali Valley and the mouth of the Colorado River are in a region where the crust of the earth is thinnest. The crust of the earth is typically about 30 km thick; but in this zone, a thickness of less than 18 km was detected.

On the other hand, and hence the uncertainty, it has been theorized that in geothermal systems of very hot water, the gradients remain constant at temperatures near the critical point. At great depths, these temperatures are maintained by convection effects; this could occur at Cerro Prieto, as illustrated in Figures 5 and 6, and also shown in the convecting geothermal model in Figure 2. However, none of these theories eliminates the possibility of finding melted rock at very shallow depths.

CONCLUSIONS

1. The geothermal gradient at Cerro Prieto of 15°C per 100 m is one of the highest measured in the various geothermal fields currently under exploitation around the world.

2. It is possible that in the Cerro Prieto field, which is a hot water reservoir, in the high temperature areas, dry steam could be extracted at depths below the actual exploitation strata, which may be interconnected with deep fractures. This possibility offers the advantage of using the total energy of the fluids, which is now partially discarded in separated water.

3. It is quite feasible that at a depth of 6 to 8 km, melted rock could be found. This would insure enormous geothermal reserves in this area, where CFE has 400 MW in operation, 220 MW more in construction and where by 1991, CFE plans to increase the electrical generation capacity to 840 MW.

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