A RESERVOIR ENGINEERING ASSESSMENT OF THE CHIPILAPA, EL SALVADOR, GEOTHERMAL FIELD

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ABSTRACT - The Chipilapa geothermal field is located near the eastern border of the well-known Ahuachapán geothermal field, in El Salvador. Six deep exploratory wells, with depths ranging between 985 and 2,700 m have been drilled there, over an area of 3.3 by 0.7 km. The present assessment is based mainly on drilling records and temperature and pressure logs, complemented with geological and geochemical results from other authors. We found that all the wells present temperature inversions, indicating that the explored area contains a relatively shallow reservoir outflow with a maximum measured temperature of 220°C. Below the temperature inversions several wells depict anomalous thermal gradients, reflecting the presence of a deep heat source, presumably *the* magmatic chamber inferred by geological and volcanological studies. Comparison of the inferred true formation temperatures wilh homogenization temperatures of fluid inclusions revealed that in the past the shallower temperatures were 20-40°C higher than current temperatures.

1. INTRODUCTION

The Chipilapa geothermal field is located near the East border of the well-known Ahuachapán geothermal field, on the western side of El Salvador (Fig. 1). *Its* convenient location made it an obvious target for exploration.

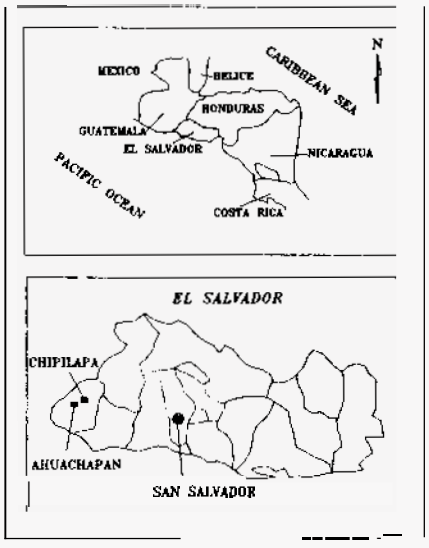


Fig.1 Location of the Chipilapa geothermal field.

Deep drilling exploration began in Chipilapa on 12 March 1968, as a collaborative effort by CEL and the United Nations. The CH-1 well reached a depth of 985 m with maximum temperature of about 220°C at 300 m a.s.l. Deep exploration drilling in Chipilapa then endured a long hiatus. It resumed in March 1989. Five deep exploratory wells have been drilled *since* then.

In this work we present a reservoir engineering assessment of the area thus explored. Our work is based mainly on drilling records and temperature and pressure logs. This basic information has been complemented with volcanological, geological, lithological and geochemical results from *other* authors. First, we inferred the permeability and *thermal* structures of each well. Then we correlated these results over the explored area.

2. THE WELLS

Chipilapa's exploratory wells were drilled in the northern dope of the Cerro Cuyanausul. They lie *on* a SE-NW trending line, covering an area of about 3.3 by 0.7 km, a few kilometers East of Ahuachapán's wellfield (Fig. 2). In general, the altitude of the wellheads decreases towards the NW (Table 1). In the vertical direction, these wells penetrated to 1642 m b.s.l. (well CH-8).

Table 1. Wellhead altitude and depth of the wells

Well	Elevation (m a.s.l.)	Depth (m)
CH-9	741	1999
CH-E1	757	450
CH-1	758	985
CH-7B	758	1348
CH-7	766	1500
CH-8	914	2556
CH-A	1148	2700

For completeness, we added to Table 1 well CH-E1, a relatively shallow, thermal gradient well. Also, note that wells CH-1 and CH-7B, which were drilled from the same pad, appear superposed on Fig. 2, due to scale.

3. THERMAL RESULTS

We assessed the thermal structure of the formations intersected by the wells from temperature logs, complemented with temperatures inferred from fluid inclusions.

The best way to observe an unperturbed temperature profile of the rock formations above and within geothermal reservoirs is by "stage testing" while the well is being drilled (e.g., Grant *et al.*, 1982, White *et al.*, 1975). Temperatures were measured in some wells during breaks in drilling, to record the temperature recovery. Care was taken that there was no circulation of fluid within the well during this period and that the depth at which the recovery was

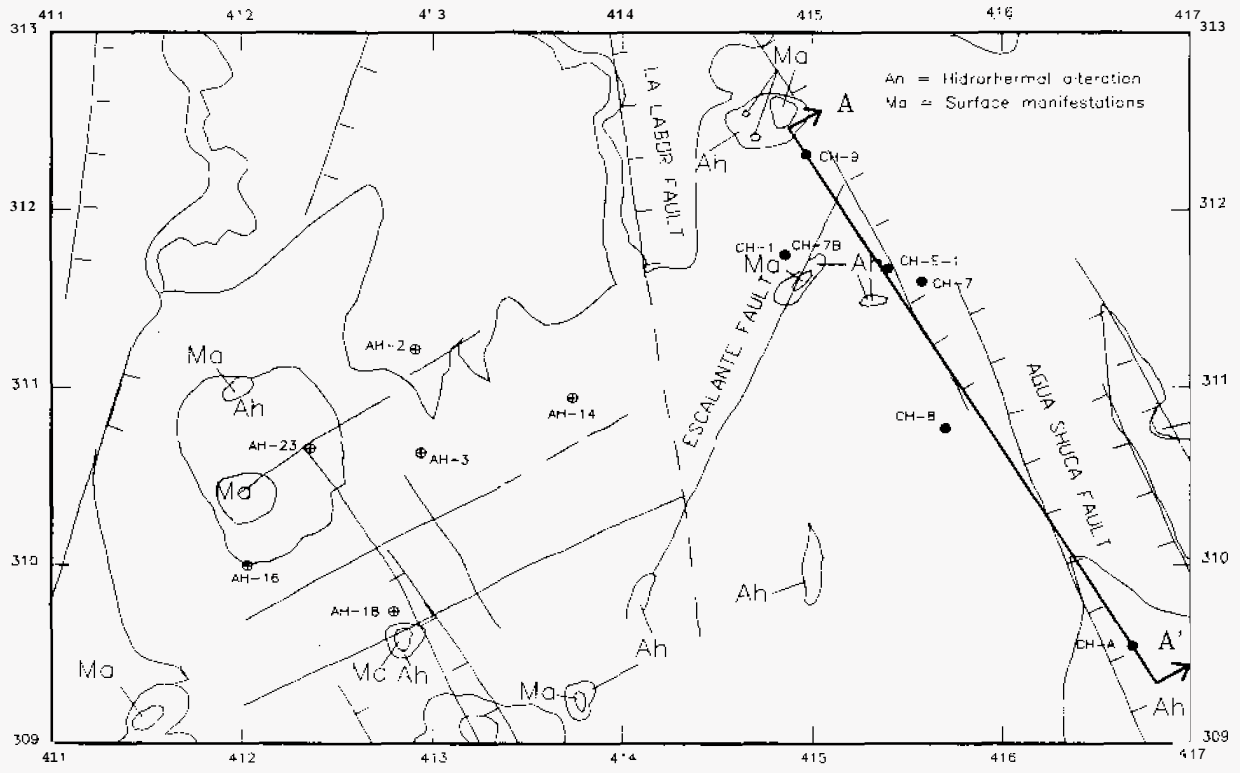


Fig. 2 Location of the Chipilapa wells; some wells from Ahuachapán also shown for reference.

observed was not a zone of lost circulation, as required by the interpretation methods. Although other methods (e.g., Roux *et al.*, 1979) have been proposed to estimate true temperatures, for this assessment we used the standard method of the Homer plot (e.g., Grant *et al.*, 1982).

Figure 3 illustrates our Homer plot for well CH-A near its final depth. In this particular case the recorded hating time exceeded 190 hours. Recorded heating times ranged from abut 6 hours to more than 80 in the remaining tests, reflecting drilling opportunities and circumstances.

Our estimated formation temperatures are shown in Figs. 4-6. Fur comparison, we have also plotted in these figures temperature logs with relatively long heating times. Of course, these logs reflect formation tempcratures only indirectly, because convection-driven circulation in the well severely distorts the profile corresponding to unperturbed furmation temperatures. Nonetheless, these logs provide important clues to the thermal structure of the explored zone (see below).

We have also shown in these figures homogenization temperatures from fluid inclusions, when available. These temperatures were taken from Iglesias et *al.* (1993, well CH-A) and from Faz-Pérez *et al.* (1991, othcr wells). At each studied depth, there is a distribution of homogenization temperatures, each spanning up to several tens of degrees Celsius. But only the minimum temperature of the distribution corresponds to the formation temperature, ai the time the fluid inclusions were trapped. For this reason, our figures show the minimum temperature of each sample distribution. Figures 7-9 present relevant thermal informationcorresponding to the remaining wells.

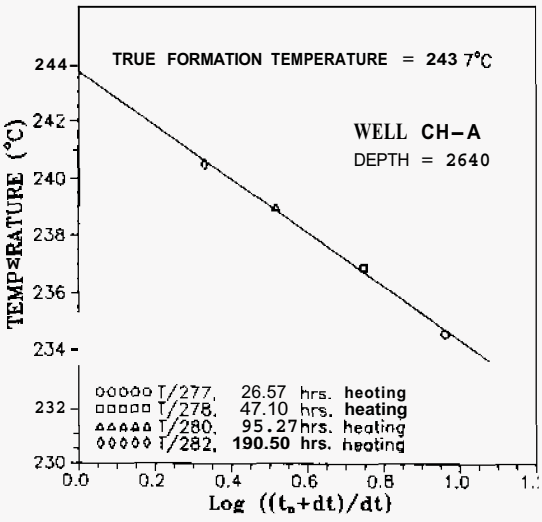
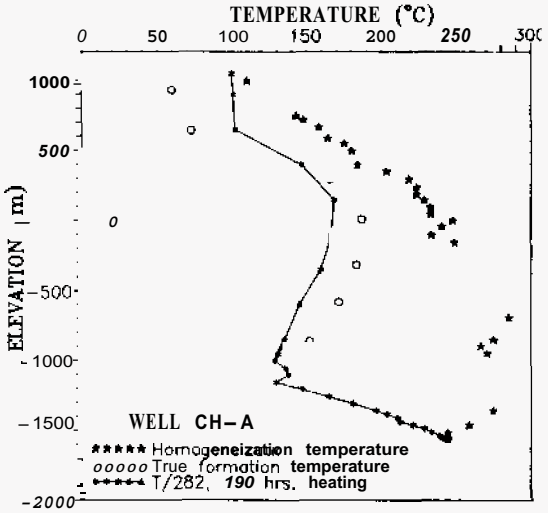


Fig. 3 Example of Homer plot used to estimate true formation temperatures.



Pig. 4 Thermal data associated with well CH-A

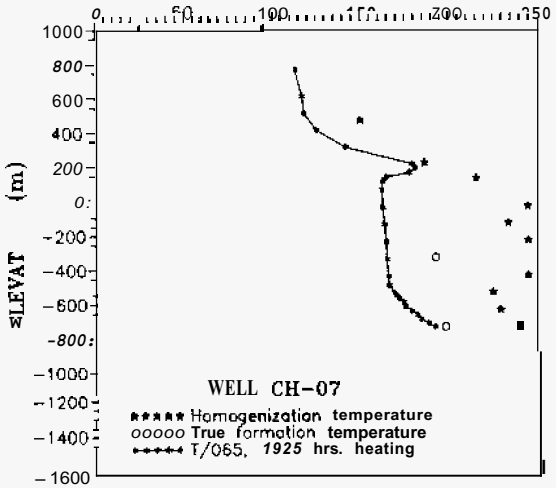
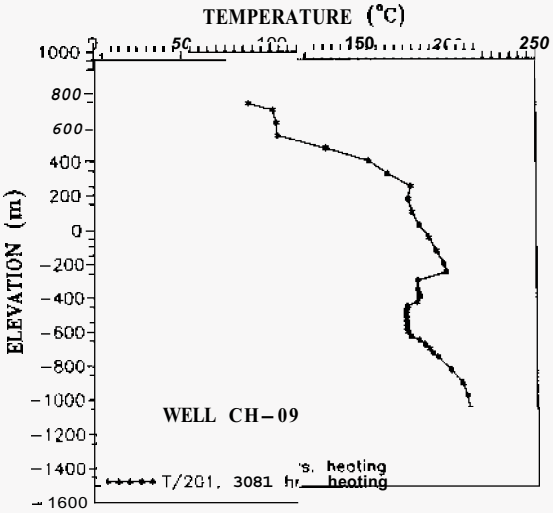


Fig. 5 Thermal data associated with well CH-7.



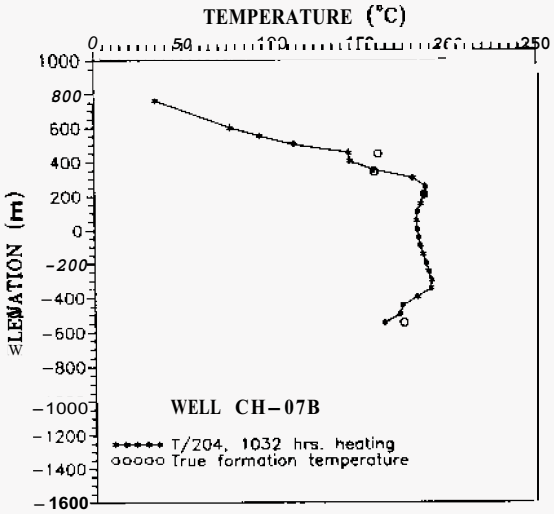


Fig. 6 Thermal data associated with well CH-7B.

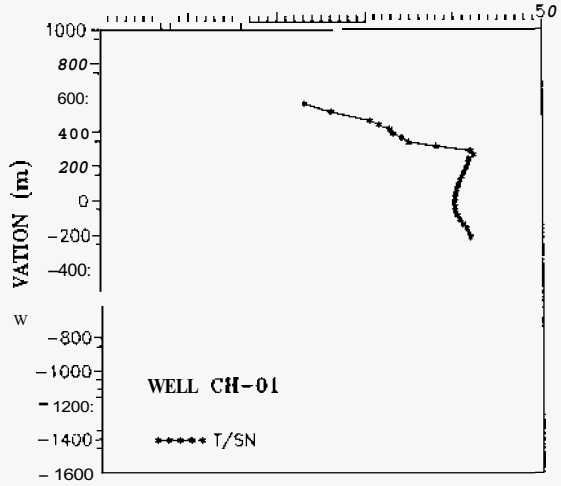


Fig. 9 Thermal data associated with well CH-1

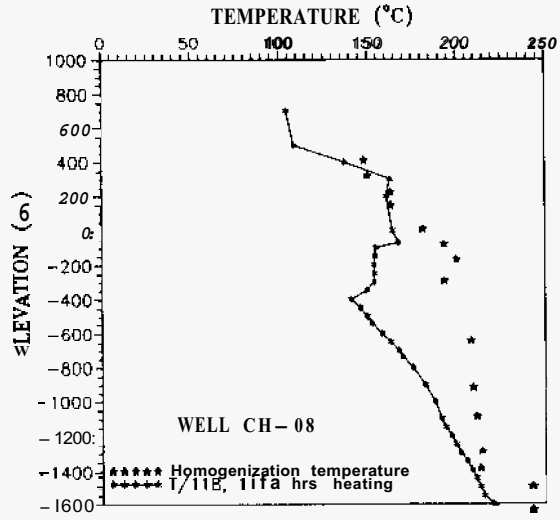


Fig. 7 Thermal data associated with well CH-8.

3. PERMEABLE ZONES

We located permeable zones in the wells mainly from temperature and pressure logs during injection tests and warm-up, using standard interpretation techniques (e.g., Grant *et al.*, 1982). These logs were supplemented with records of lost circulation during drilling and lithological records. Figures 10-15 show temperature logs during warm-up and the inferred location of permeable zones (indicated by arrows). Note that the spatial resolution of the logs controls the accuracy of the inferred locations.

All the wells intercept from a few to several discrete permeable zones, and display long (hundreds to thousands of meters), nearly impermeable stretches. This is, of course, a signature of fractured reservoirs, an expected result given the volcanic setting of the Chipilapa prospect.

4. DISCUSSION

To correlate our results over the explored area, Fig. 16 presents pseudosection A-A', which runs from well CH-A to well CH-9 (Fig. 2). The remaining wells are projected on the plane of the pseudosection. For this reason, the wellhead elevations of some

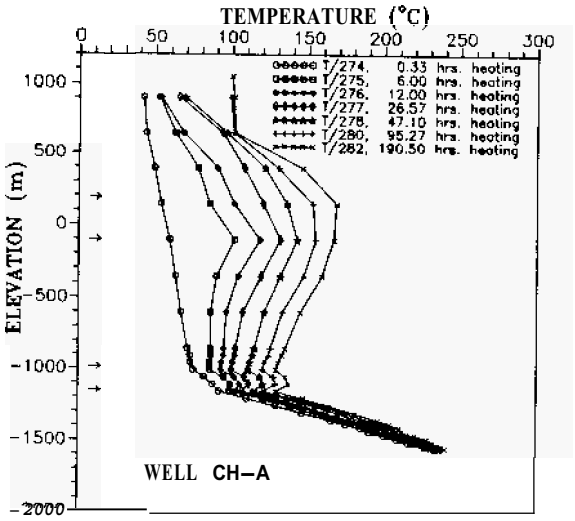


Fig. 10 Permeable zones of well CH-A.

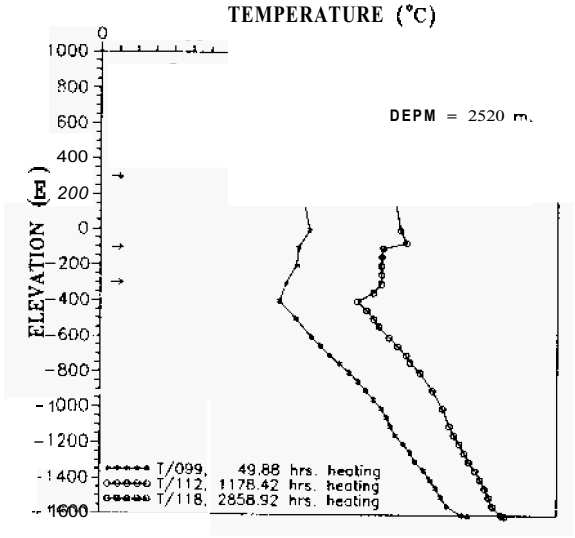


Fig. 13 Permeable zones of well CH-8.

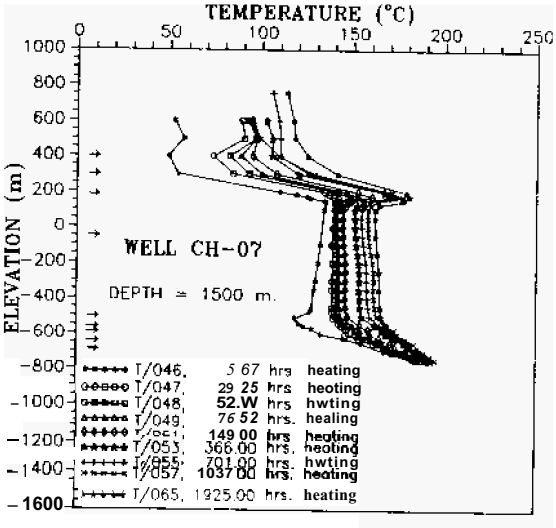


Fig. 11 Permeable zones of well CH-7.

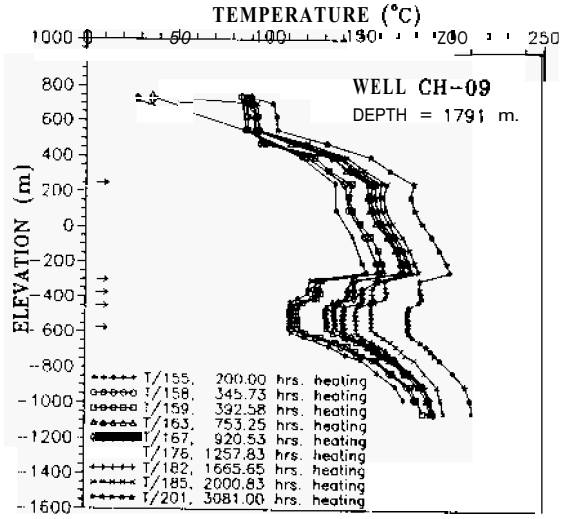


Fig. 14 Permeable zones of well CH-9.

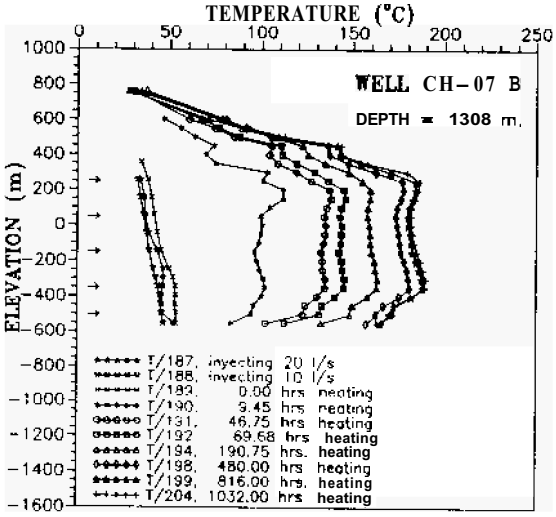


Fig. 12 Permeable zones of well CH-73.

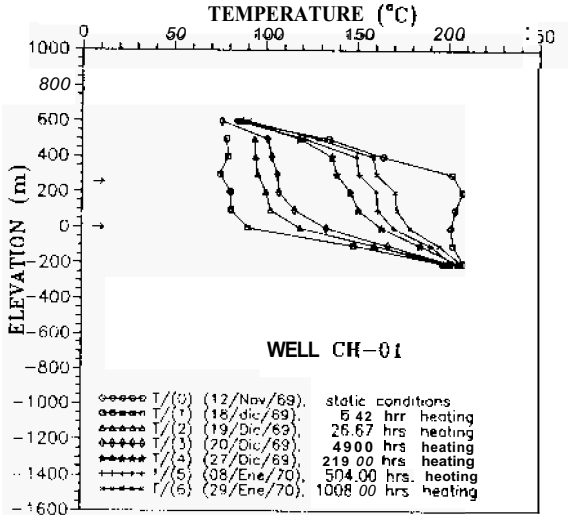


Fig. 15 Permeable zones of well CH-I

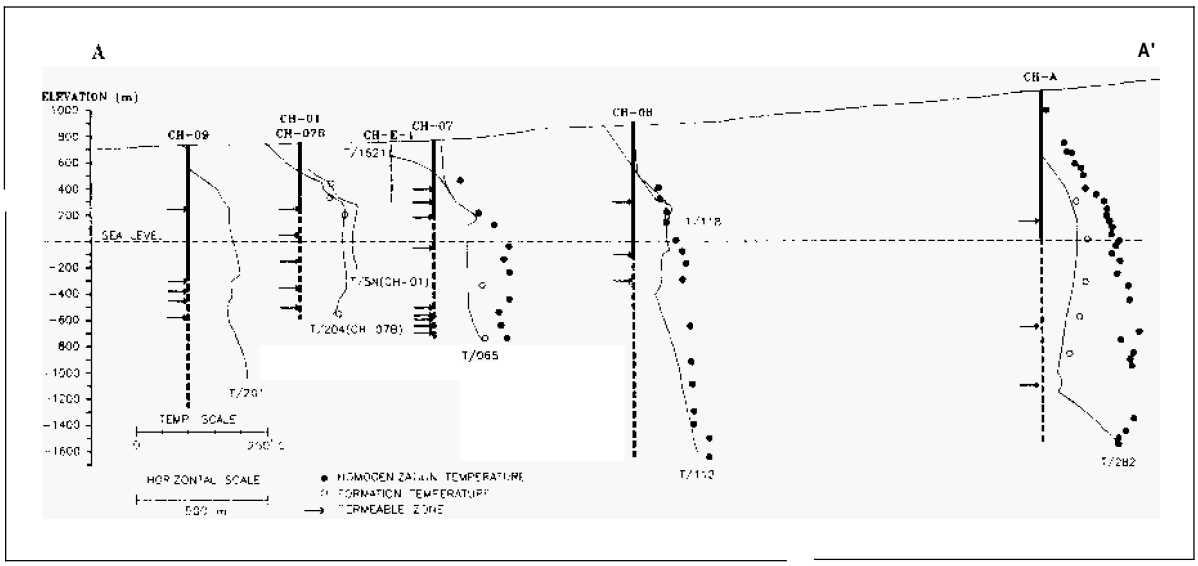


Fig. 16 Summary of thermal and permeability results.

intermediate wells do not coincide exactly with the elevation of the terrain in this figure. Vertical exaggeration is 2 to 1. Well completions are indicated by thick solid lines for cased sections, thick dashed lines for slotted liner or open hole and thin dashed line for the thermal gradient well. The temperature scale should be used as indicated in well CH-9, with the 100°C tick mark coinciding with the axis of the well.

All the wells present temperature inversions, except CH-E-I, which is probably too shallow to reveal this feature (Figs. 4-9 and 16). Temperature maxima within the inversion interval (roughly from +400 to -400 m a.s.l.) correlate well with inferred permeable zones (Figs. 10-15 and 16). Thus, the formations in this interval were most likely heated by the hydrothermal fluid, not the olher way around. And one may safely conclude that this zone contains a relatively shallow reservoir outflow.

Measured temperatures in this outflow zone lie within 160-220°C (Figs. 4-9). These temperatures are consistent with reservoir fluid temperatures inferred from cationic geothermometers (e.g., Nieva *et al.*, 1992) for the exploration wells. Both measured and inferred temperatures are up to several tens of degrees Celsius lower than pre-exploitation temperatures in Ahuachapán (e.g., 214-240°C, Laky *et al.*, 1989; 240-260°C, Truesdell *et al.*, 1989). Furthermore, the salinity of the fluids discharged by these wells (about 2,000 ppm Cl^- for CH-7 and CH-8 and about 3,700 ppm Cl^- for CH-7B and CH-9, at reservoir conditions) is considerably smaller than that of Ahuachapán fluids (about 7,000-8,000 ppm Cl^-, Truesdell *et al.*, 1989) and comparable to that predicted (2.200-2,450 ppm Cl^-) by the geochemical model of Nieva *et al.* (1992). Interestingly, this model includes a well documented outflow from Ahuachapán towards Chipilap. All thew observations consistently indicate that the outflow discussed in the preceding paragraph is an outflow of the Ahuachapán hydrothermal system.

Below the temperature inversions, the deeper wells (CH-A, CH-8, CH-9 and CH-7) appear nearly impermeable (Figs. 10-15). Anomalous thermal gradients characterize this deep zone (Pigs. 4-9). We interpret these gradients as reflecting the presence of a deep heat source. Presumably this heat source is the magmatic chamber inferred by González-Partida *et al.* (1991) from geovolcanological studies. The maximum temperature measured in this deep zone is 250°C at 1,500 m b.s.l. (well CH-A, Fig. 10).

Minimum homogenization temperatures from fluid inclusions record the formation temperature at the time the fluid inclusions were trapped. In Chipilapa, the minimum homogenization temperatures from fiuid inclusions resulted, in general, significantly higher than the inferred true formation tempcratures (Figs. 4, 5 and 16). Note, however, that at the bottom of the deeper wells formation and homogenization temperatures tend to converge (Figs. 4 and 7). These results indicate that in the past the temperatures within the explored area in Chipilapa were generally about 20-40°C higher than the current temperatures. Similar results were found for the Miravalles geothermal ficld (Bargar and Foumier, 1988).

5. CONCLUSIONS

We found that the explored area contains a relatively shallow (roughly, from +400 to -400 m a.s.l.) outflow of the Ahuachapán hydrothermal system. Fluid temperatures in this outflow span the range 160-220°C.

Our results also indicate that in the past the temperatures in Chipilapa were typically 20-40°C higher than the current temperatures.

Finally, we concluded that below the outflow the thermal structure of the Chipilapa field reveals the presence of a deep heat source. Presumably this heat source is the magmatic chamber inferred by previous geovolcanological studies.

6. ACKNOWLEDGEMENTS

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