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SOME COMMENTS ON THE LA PRIMAVERA GEOTHERMAL FIELD, MEXICO

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ABSTRACT

The La Primavera geothermal field is located about 20 km west of the city of Guadalajara, Jalisco, in the western part of the Mexican Neovolcanic Axis. Initial results of five deep exploration wells (down to 2000 m depth) were very promising; measured downhole temperatures exceed 300°C. During production, however, downhole temperatures dropped, and the chemistry of the fluids changed. The analysis of geologic, mineralogic, geochemical, and well completion data indicate that colder fluids flow down the wellbore from shallower aquifers cooling the upper zones of the geothermal reservoir. This problem is attributed to inadequate well completions.

Doubts have arisen about continuing the exploration of the field because of the somewhat disappointing drilling results. However, a more thorough analysis of all available data indicates that a good geothermal prospect might exist below 3000 m, and that it could be successfully developed with appropriately located and completed wells.

INTRODUCTION

The La Primavera geothermal field lies in the late Pleistocene ryholitic complex of the same name, located about 20 km west of Guadalajara, Jalisco, Mexico (Fig. 1). Associated with faults related to caldera collapse and later magma injection, the Sierra La Primavera contains abundant fumaroles near its center and large-volume hot springs around its western boundary (Mahood et al., 1983). The temperature of these springs is about 65°C, their discharge is significant, i.e.: Río Caliente (73 L/s), Arroyo Verde (43 L/s), and Agua Brava (156 L/S). Because of these important surface manifestations the Comisión Federal de Electricidad (CFE) began in 1978 a program of geothermal exploration and evaluation. By late 1980 the first exploratory well was completed; presently five deep wells have been drilled within the caldera (Fig. 2).

The initial results of the exploratory drilling were encouraging. However, the prospects for a commercial system became less bright mainly because of a reduction in downhole temperatures as the wells were allowed to flow. We summarize in this paper the data obtained from the La Primavera wells and we offer an explanation as to the behavior of the wells during production. Finally, the location and completion of new wells, and the deepening of some of the existing ones is proposed.

AVAILABLE DATA

The bulk of the information on the exploration and development of the La Primavera field is contained in internal CFE reports, written in Spanish (Benegas, 1983; Casarrubias, 1983; Gutiérrez, 1983; Munguía, 1983; Pérez, 1983; Ramírez, 1983; Romero, 1983; Torre, 1983; Villa, 1983). One of the purposes of this paper is to make available part of this information.

Mahood (1980, 1981a, and b) extensively studied the geology and petrology of the Sierra La Primavera. She characterizes the system as a late Pleistocene rhyolitic center consisting of lava flows and domes, ash flow tuffs, air fall pumices, and caldera lake sediments. Recently, Mahood et al. (1983) published the results of a reconnaissance geochemical study of the geothermal area itself. Their model of the geothermal system suggests that the heat source could be a melt zone or magma chamber approximately 15 km in diameter and 2-5 km below the surface. Most of the shallow heat would be available where permeable zones associated with deep faults have permitted convection of hydrothermal fluids.

According to Mahood et al. (1983) the geothermal reservoir is largely in volcanic rocks that predate the Primavera caldera, consisting of silicic ash-flow tuffs and lava flows, and andesitic to basaltic lavas. Therefore, the reservoir rocks will present a wide range of permeabilities and porosities. Their model shows (Fig. 3) that near the center of the Sierra La Primavera hot water (>300°C) rises to shallow depths, where it boils to form a shallow vapor-dominated zone. Steam of this zone heats meteoric water in a shallow, high permeability aquifer (in the Tala Tuff) from which steam separates at about 170°C. Part of the steam escapes to the surface through fault-related fractures cutting the less permeable zones of the Tala Tuff which act as a cap rock to the geothermal system. The remaining geothermal fluid then flows laterally as a two-phase fluid, cooling by conduction, emerging as hot (about 65°C) springs at the western margin of the Sierra.

The mass recharge to the geothermal system indicated by the downward arrows shown in Figure 3, could be significant. According to Ramírez (1983) the potential infiltration in the area would be approximately 5.9 x 10^6 m^3/year. However, not all of it would reach the geothermal reservoir, part will feed the important near-surface aquifer. The leakage of meteoric waters to the geothermal reservoir is rather slow. On the basis of tritium analyses, Mahood et al. (1983) indicate a minimum age for the geothermal waters of 50 years.

WELLS

To date five exploratory wells have been drilled at the La Primavera geothermal field (Fig. 2): Primavera 1 (PR-1), Río Caliente 1 (RC-1), Primavera 2 (PR-2), Primavera 4 (PR-4), and Primavera 5 (PR-5). They are located in, or near, areas of geothermal manifestations. Each well was drilled to intersect the structures (faults, fractures) which permit the ascent of geothermal fluids from depth. Well data on the lithology, cutting mineralogy, lost circulation, completion, and temperature will be described below.

Primavera 1 (Fig. 4). This is the first deep well drilled in La Primavera. It is located in the fumarole area of "Las Barrancas" in the southern part of the caldera; its total depth is 1226 m. The lithologic column in PR-1, as in all La Primavera wells, is composed mainly by pyroclastic and volcanic rocks.

Important fractures were encountered, resulting in high, and sometimes total, circulation losses. These zones occurred mainly in the Tala Tuff between 36 and 380 m depth, and below 700 depth. The mineralogy of the cuttings indicate moderate temperatures, especially in the upper 1000 m; pyrite and epidote appear near the bottom of the hole.

During the drilling of the upper 600 m the temperature of the mud at the outlet never exceeded 52°C, and the difference between inlet and outlet temperatures was small. However, for some zones between 690 and 1100 m depth (corresponding to lost circulation zones) the outlet mud temperature exceeded 60°C. For that interval, the average maximum outlet temperature was 40°C and the inlet-outlet difference sometimes was greater than 10°C. Toward bottomhole the outlet mud temperature reached and exceeded 60°C, and the temperature difference was only about 5°C. With a static mud column in the borehole for 25 hours, the temperature near the bottom of the well was slightly above 200°C.

The completion of the well is shown on Figure 4. A long slotted liner was installed between 659 and 1159 m, allowing the communication between different feed zones of contrasting temperatures. This was reflected by the behavior of the well during production, as will be discussed below.

Río Caliente 1 (Fig. 5). RC-1 was drilled near the western edge of the caldera, in an area of high-discharge hot springs. It was intended to intersect the high-angle faults bounding the caldera.

The 1900-m deep well was drilled through rocks with few fractures; no circulation losses were observed. The mineralogy of the cuttings, the temperature of the drilling mud and the downhole temperature profiles indicate that RC-1 is a low temperature well. The borehole was left open below 297 m depth.

The model of Mahood et al. (1983) (Fig. 3) shows that this well was drilled in a discharge area, away from the hot water source near the central part of the caldera.

Primavera 2 (Fig. 6). This well is located in the central part of the caldera, in the "La Azufrera" area where vigorous sulfur-depositing steam vents exit. Drilled to 2000-m, PR-2 is the deepest La Primavera well.

Important loss-of-circulation zones were encountered in the upper 500 m, mainly in the Tala Tuff, and below 1500 m, in the microlitic andesites. Generally, the cutting mineralogy indicates moderate temperatures. However, epidote was observed at about 500 m, suggesting higher temperature alteration associated with a fault intersected at that depth. Epidote was also found near bottomhole; pyrite occurred between about 800 and 1300 m, and below 1600 m depth.

The outlet mud temperature during drilling sometimes exceeded 70°C; the inlet-outlet temperature differential, 10°C. The highest mud temperatures were observed between about 1600 and 1800 m depth, related to the partial lost circulation zones. The downhole temperatures measured after 24 hours with a static mud column in the borehole indicate boiling at about 700 m depth, and a maximum temperature of about 265°C at bottomhole.

Casing was installed and cemented to 998 m depth, and a partially slotted liner was suspended below it. The open part of the liner, below 1567 m depth, is adjacent to the zone of highest measured temperatures. However, the long open hole interval, behind the liner, allows the down-flow of colder waters within the borehole influencing the production characteristics of the well. A maximum temperature of 307°C at 2000 m, with a static water column in the wellbore, was recorded.

Primavera 4 (Fig. 7). PR-4 was drilled to a total depth of 668 m in the Cerritos Colorados graben, an area of active fumaroles. During drilling serious circulation problems were encountered, requiring the use of air and foam for some zones. All data indicate low temperatures for the drilled interval. The fractures in the microcrystalline rhyolite and Tala Tuff not only create drilling problems but also allow deep infiltration of shallow, cold ground waters, "drowning" any possible geothermal anomaly. Casing was cemented to 305 m depth. Below that the borehole is open except for a cement plug between 637 and 668 m.

Primavera 5 (Fig. 8). This well is located 580 m east of PR-1; its total depth is 1215 m. Major lost circulation problems were encountered which, sometimes, even prevented the retrieval of cuttings.

The mineralogy of the cuttings, the temperature of the mud during drilling, and the temperature profiles in the mud colum after 61 hours of static conditions--showing a maximum temperature of about 230°C--indicated better thermal conditions than in the other four wells.

PR-5 was completed with cemented casing and liner down to 879 m in an attempt to isolate the lower units from colder aquifers above. However, the slotted liner installed between 879 and 1213 m was left open to some of the moderate temperature zones in the lithic tuffs where some major circulation losses occurred. This allows the intrusion of colder fluids into the deeper part of the borehole and reservoir.

HYDROTHERMAL ALTERATION

The distributions of lithologies and hydrothermal alteration as determined from well cuttings, are shown schematically in Figure 9. The nonuniform percentage of alteration minerals reflects the interaction of the rocks with waters of different temperatures. Where higher temperatures are found, such as where hotter fluids ascend through faults and fractures, a larger percentage of alteration is observed. Conversely, where colder waters circulate and descend along faults and fractures, the alteration is less prevalent.

Figure 9 clearly indicates the highest temperatures toward the south-central part of the caldera, near wells PR-1 and PR-2, and the lowest temperatures towards its periphery (e.g. well RC-1). This thermal structure is consistent with Mahood et al's. (1983) model (Fig. 3).

BEHAVIOR OF WELL PR-1

To illustrate the characteristics of the La Primavera field, the behavoir of well PR-1 is discussed. The temperature logs taken after drilling completion are shown in Figure 10. After 25 hours with a static column of water in the borehole the highest measured temperature, about 210°C, was at total depth. During the well warmup period (Fig. 11) significant temperature increases were observed. Bottomhole temperatures above 280°C were measured.

The changes in the temperature profiles with production are shown in Figure 12. The first two logs (T-59 and T-60) taken with the well producing through a 10-in.-diam. line show rather low temperatures, possibly because some of the large volumes of cold water injected into the formation during drilling (about 3200 m^3 between 700 and 1226 m depth) are flowing back into the borehole. Profiles T-61 and T-62 (well flowing through two 2-in.-diam. lines) indicate a general increase of temperature with time. Log T-63 (well producing through a 1-1/2-in.-diam. orifice) shows the highest temperatures (maximum about 255°C) because of the low flow rate.

The later profiles T-66, 67 and 70 (well flowing through a 3-1/2 inch orifice or a 4-1/2 inch nozzle) indicate a significant drop in temperatures; the maximum measured is about 235°C. A break in the profile is shown between 800 and 900 m depth, indicating the influx of colder water. During drilling a zone of partial lost circulation was encountered at about 880 m (Fig. 4). The evolution of the downhole temperature profiles with time and production, indicates that more than one zone is feeding the well. The communication between aquifers of different temperatures behind the long slotted casing, is affecting adversely the production characteristics of this well. Similar behavior was observed in other La Primavera wells.

When a well intersects multiple feed zones, its performance during production might be unstable in response to the entrance of fluids of different enthalpies at various times (Grant et al., 1979). In PR-1 some instabilities are evident from variations in the chemistry of the produced fluids (Fig. 13). The fluid samples were taken during and after the time the downhole temperatures discussed above were measured. Until about February 1981 the produced fluids show an increasing proportion of geothermal waters, and a decreasing amount of low temperature injected water. After that time, there is general slow decrease in chloride, silica and boron, and an increase in bicarbonate and sulfate. These changes reflect an increasing proportion of colder waters in the fluids produced by PR-1. The oscillations in the content of some of these components could be due to the instabilities in the well resulting from its multiple feed zones.

SUMMARY AND CONCLUSIONS

The five wells completed to date at La Primavera indicate that the highest temperatures in the field are found in the south-central part of the caldera where faults and fractures carry geothermal fluids to shallower depths. In that area, a temperature of 307°C was measured in well PR-2 at 2000 m depth. Temperatures slightly above 200°C were recorded at 1200 m in wells PR-1 and PR-5.

With the exception of RC-1, important lost circulation zones, associated with fractures and contacts, were encountered. Because of the way the wells were completed with long open intervals, communication between different feed zones occurs, resulting in downflow of colder water in the borehole and progressive cooling of the produced fluids.

The mineralogy of the cuttings correlates well with the temperature of the formations at depth. Zones permeated by colder waters leaking from shallow aquifers show low percentage of alteration minerals; in areas where upflow of geothermal fluids occurs, the percentage is high.

On the basis of the data obtained from the five wells, it is felt that temperatures above 300°C could be found at about 2000 m depth in the area of wells PR-1 and PR-5. These wells could be deepened or new wells could drilled in that part of the caldera. Another region to be explored with drilling is south of these two wells, where the distribution of alteration minerals and the geologic structure suggest the existence of high subsurface temperatures. The exploration wells should be at least 3000 m deep, preferably 3500 m.

Based on the experience gained from the existing wells we emphasize that the completion of any new well should be carefully designed using all available data, in order to isolate the geothermal aquifers from colder, shallower water-bearing zones. Only with these deeper and properly designed wells will one be able to evaluate the geothermal potential of the La Primavera field.

ACKNOWLEDGEMENTS

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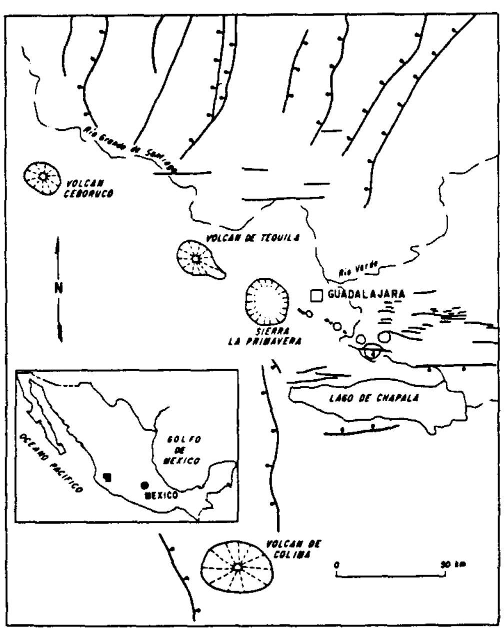

Figure 1. Location of the Sierra La Primavera, west of Guadalajara, Jalisco, Mexico (from Mahood, 1980).

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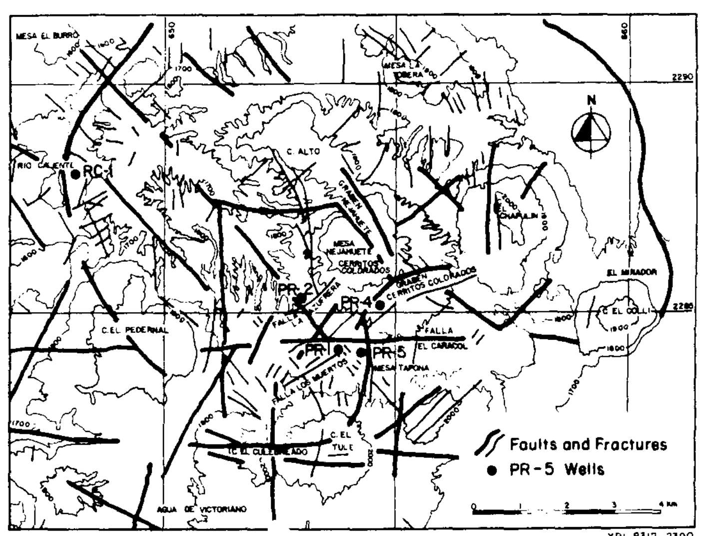

Figure 2. Structural map of the La Primavera field showing the location of the exploration wells.

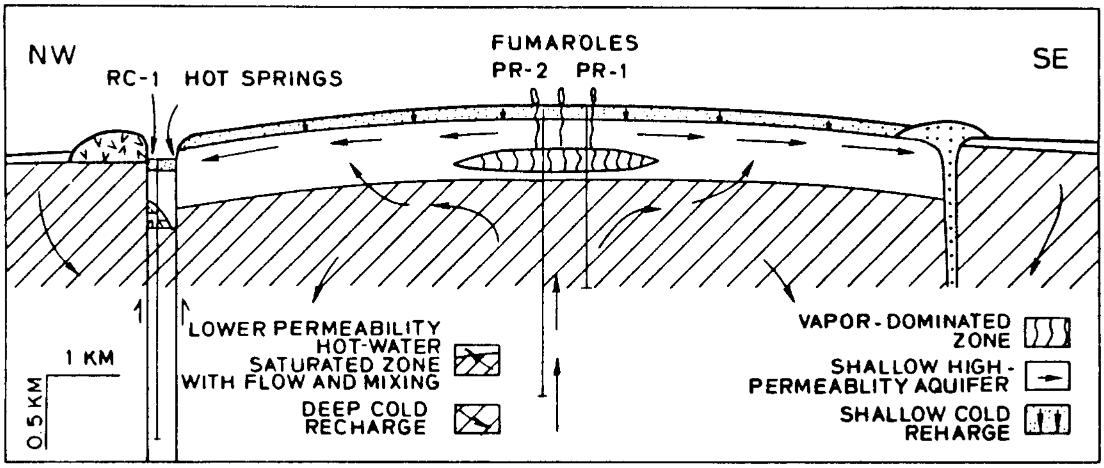

Figure 3. Schematic model for the La Primavera geothermal system developed by Mahood et al. (1983). Diagonal ruling, pre-Primavera volcanic rocks; V-pattern, precaldera lavas; unpatterned, (mainly) Tala Tuff; light stipple, lacustrine sediments; rectilinear dots, ring domes.

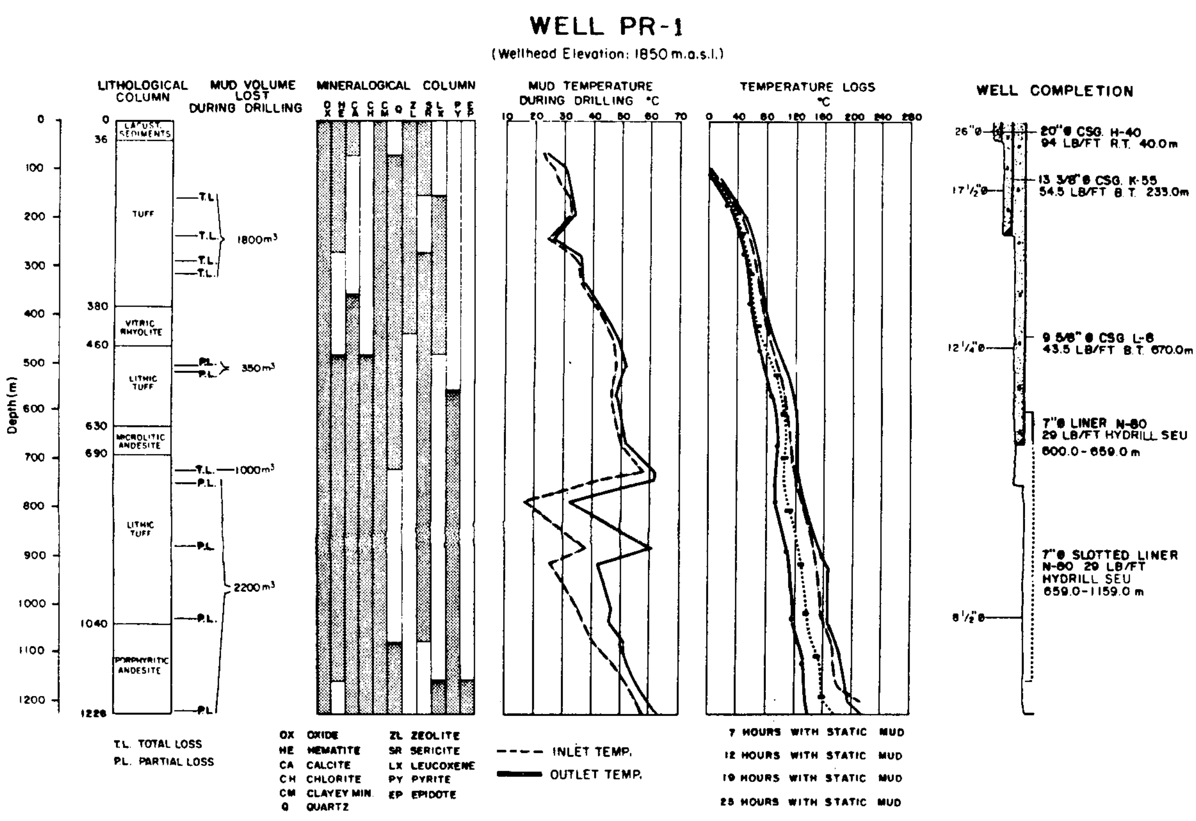

Figure 4. Well PR-1. Drilling and completion data.

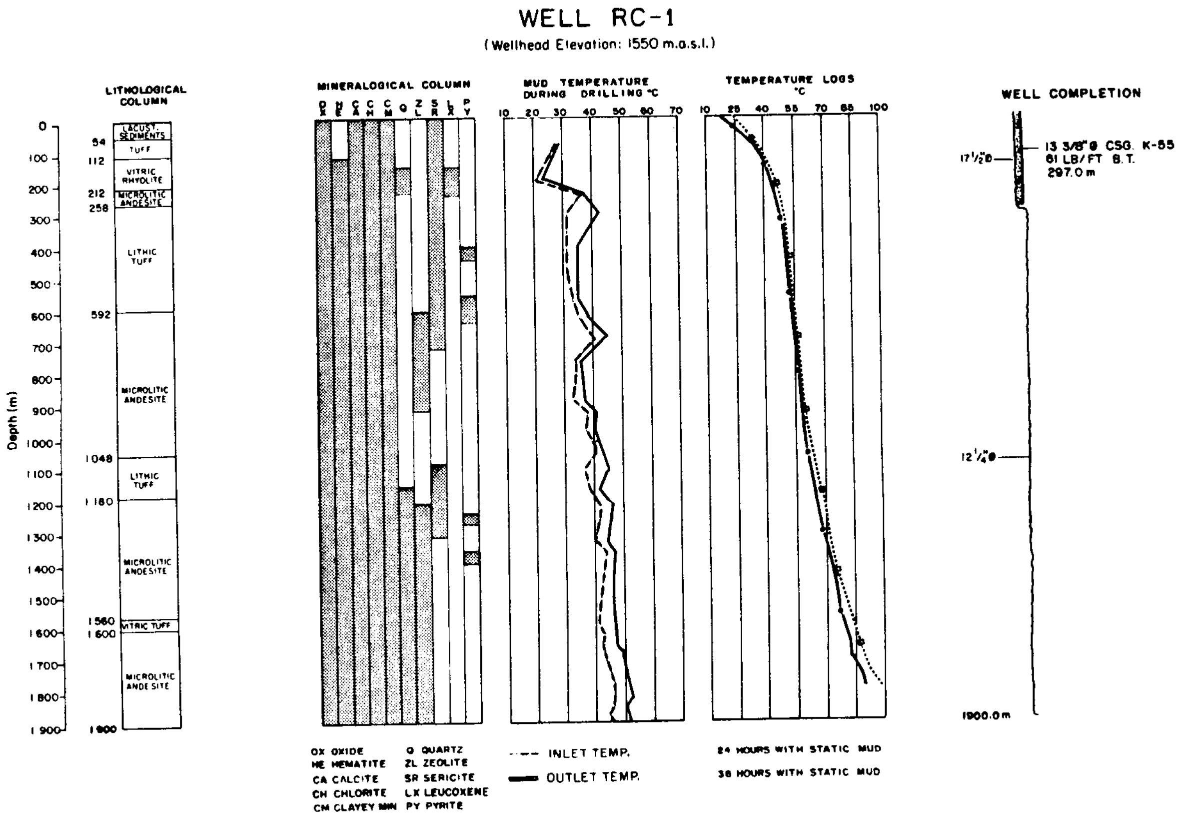

Figure 5. Well RC-1. Drilling and completion data.

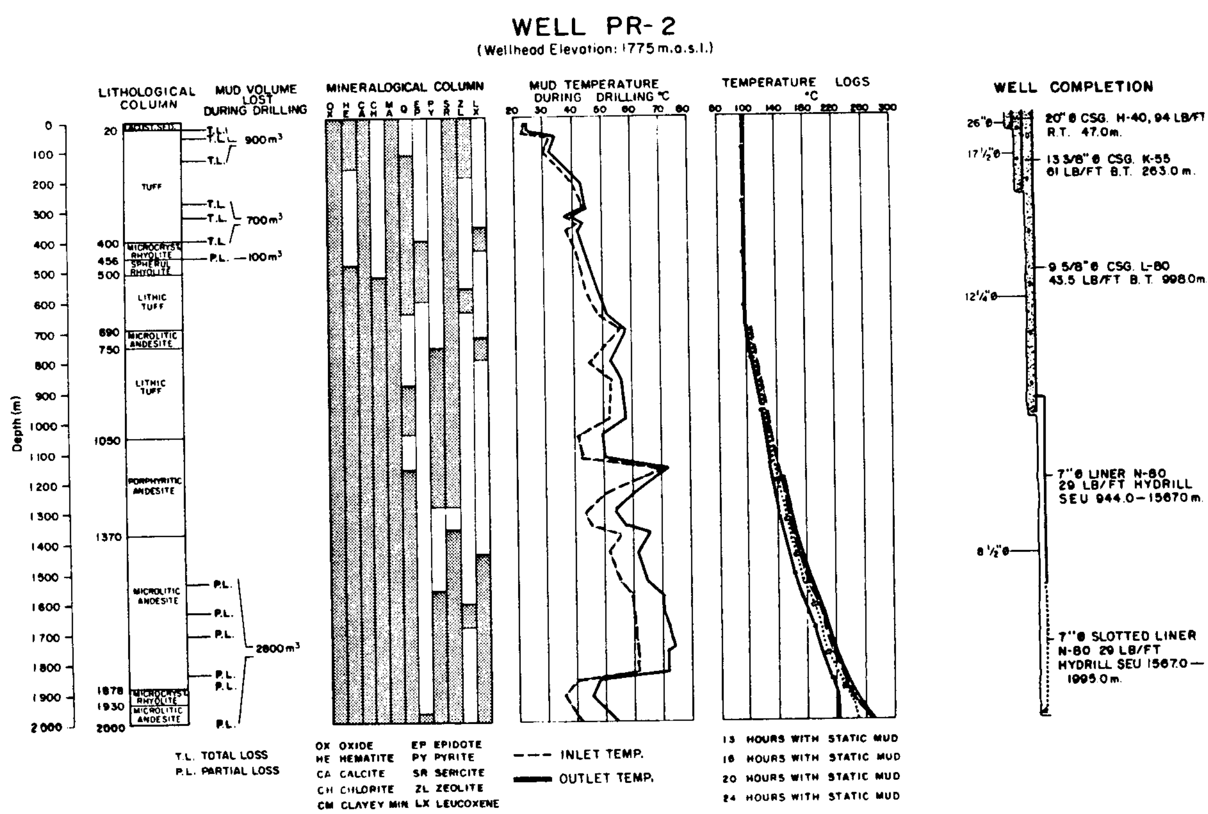

Figure 6. Well PR-2. Drilling and completion data.

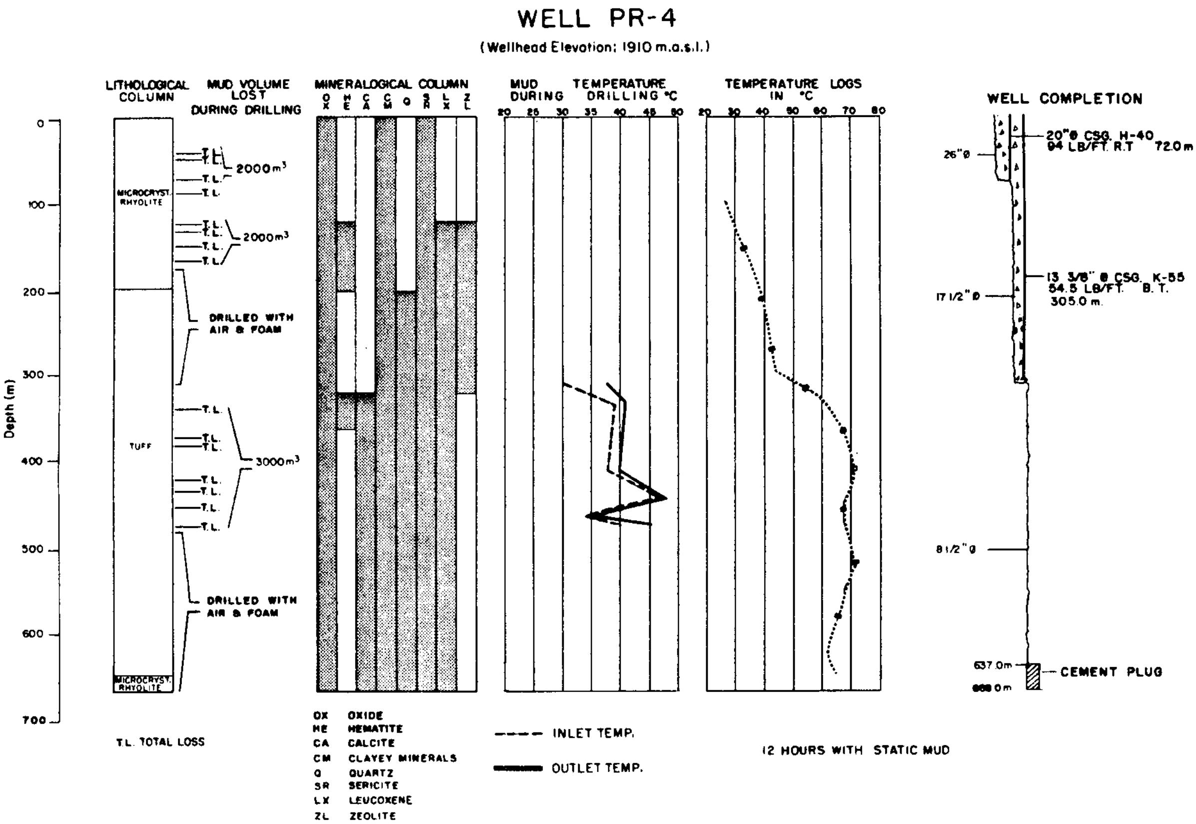

Figure 7. Well PR-4. Drilling and completion data.

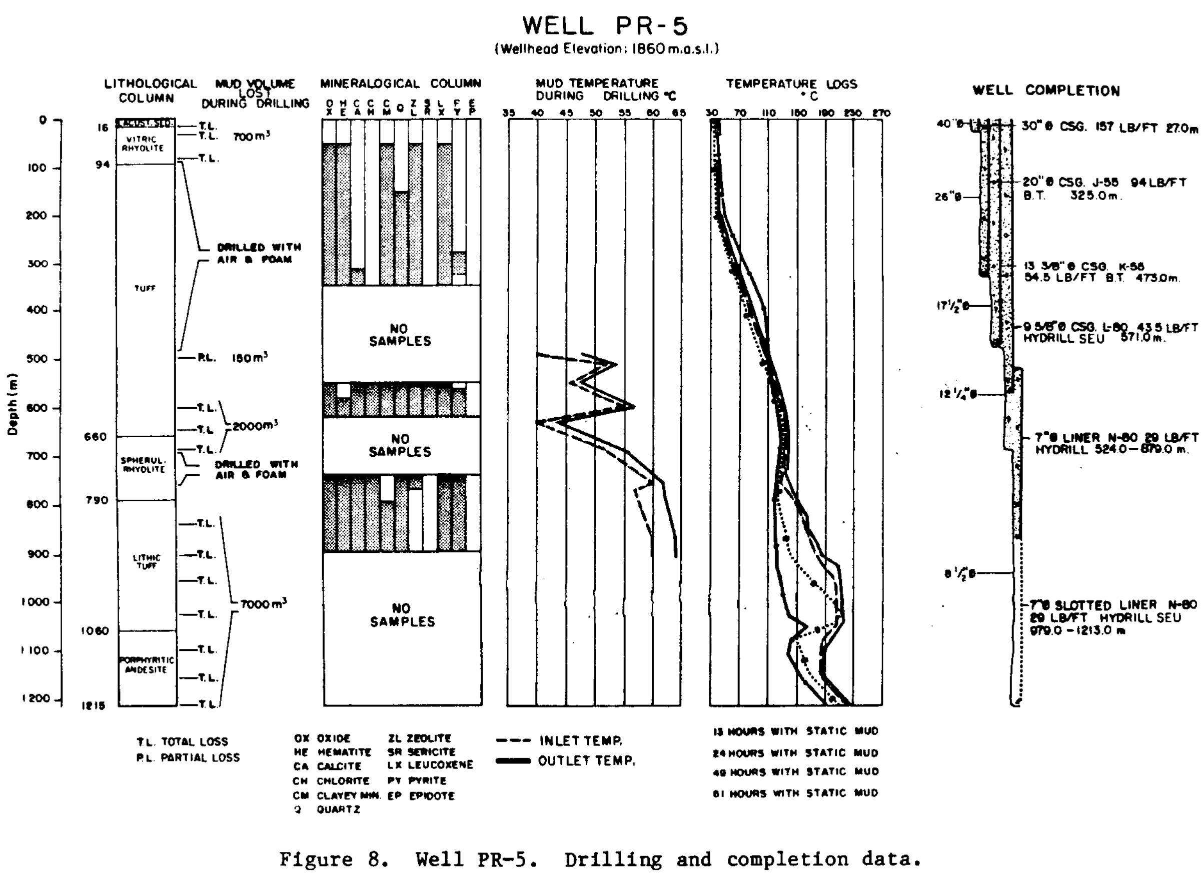

Figure 8. Well PR-5. Drilling and completion data.

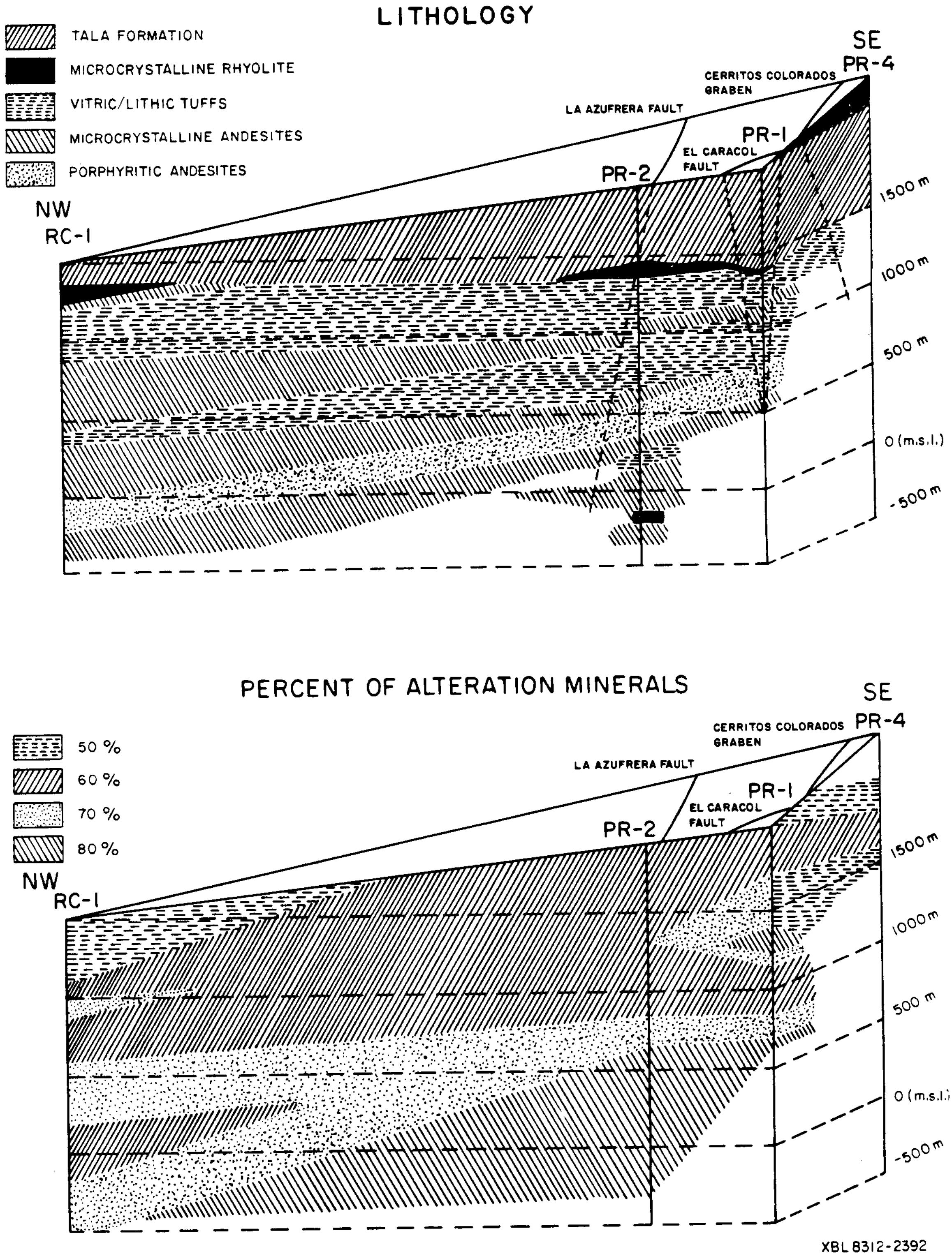

Figure 9. Distribution of lithologies and alteration minerals in the La Primavera geothermal field.

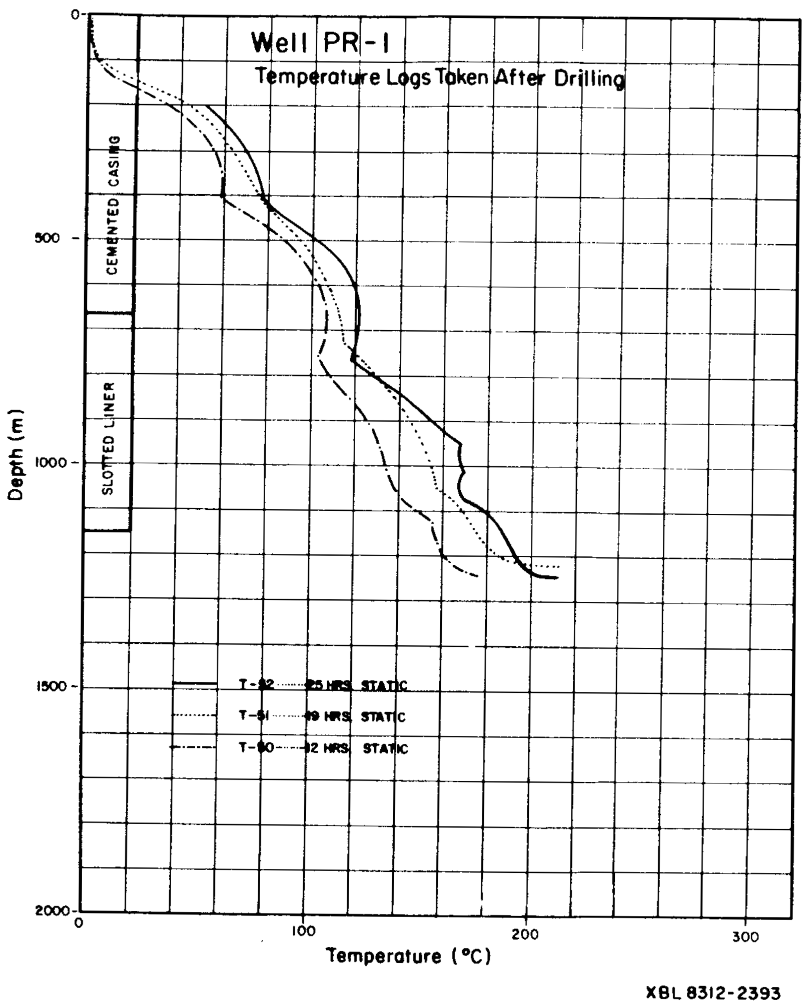

Figure 10. Well PR-1. Temperature logs taken after completion of drilling.

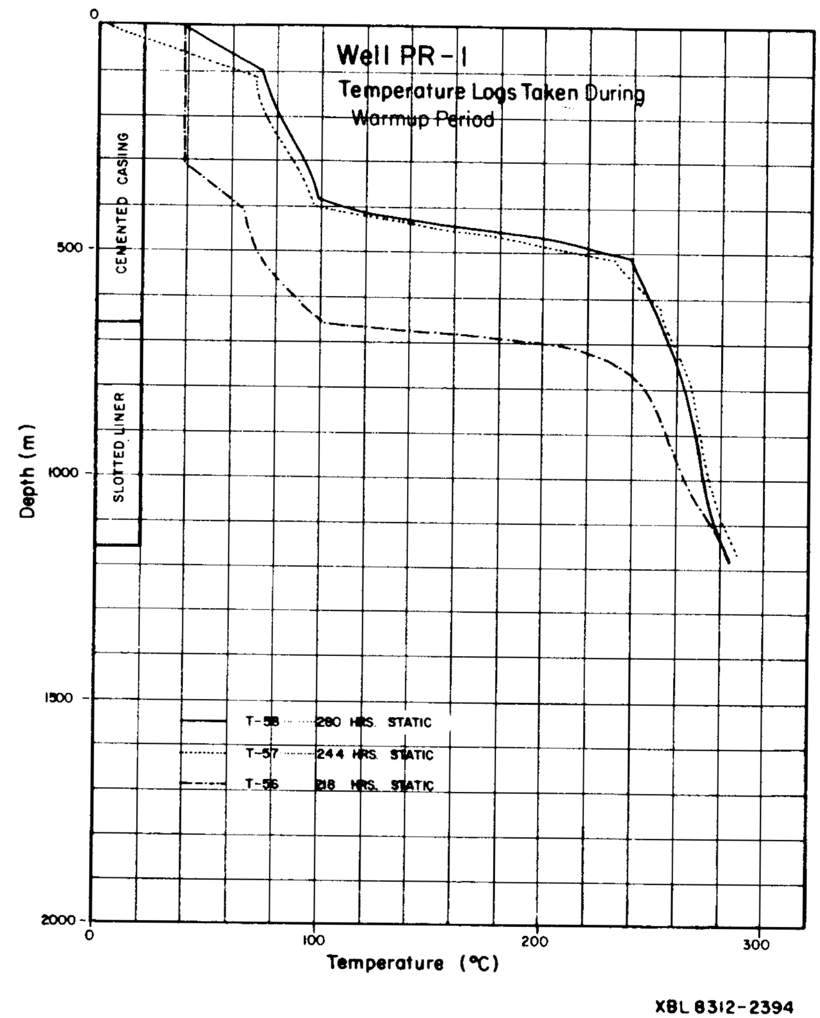

Figure 11. Well PR-1. Temperature logs taken during warmup period.

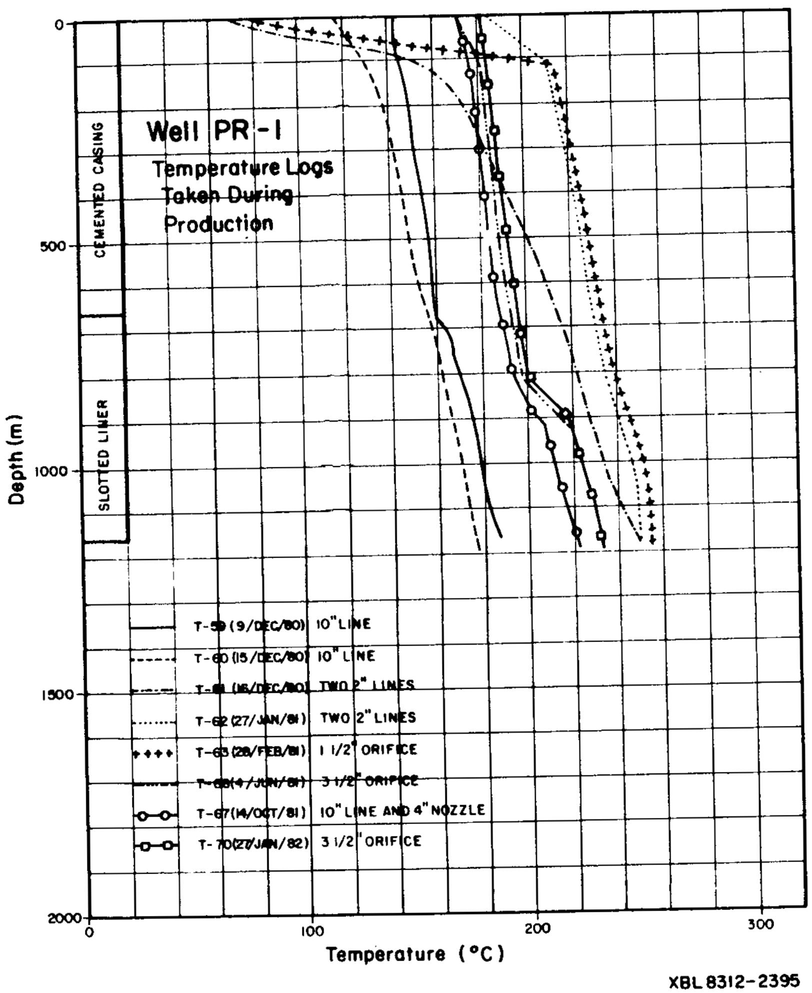

Figure 12. Well PR-1. Temperature logs taken during production.

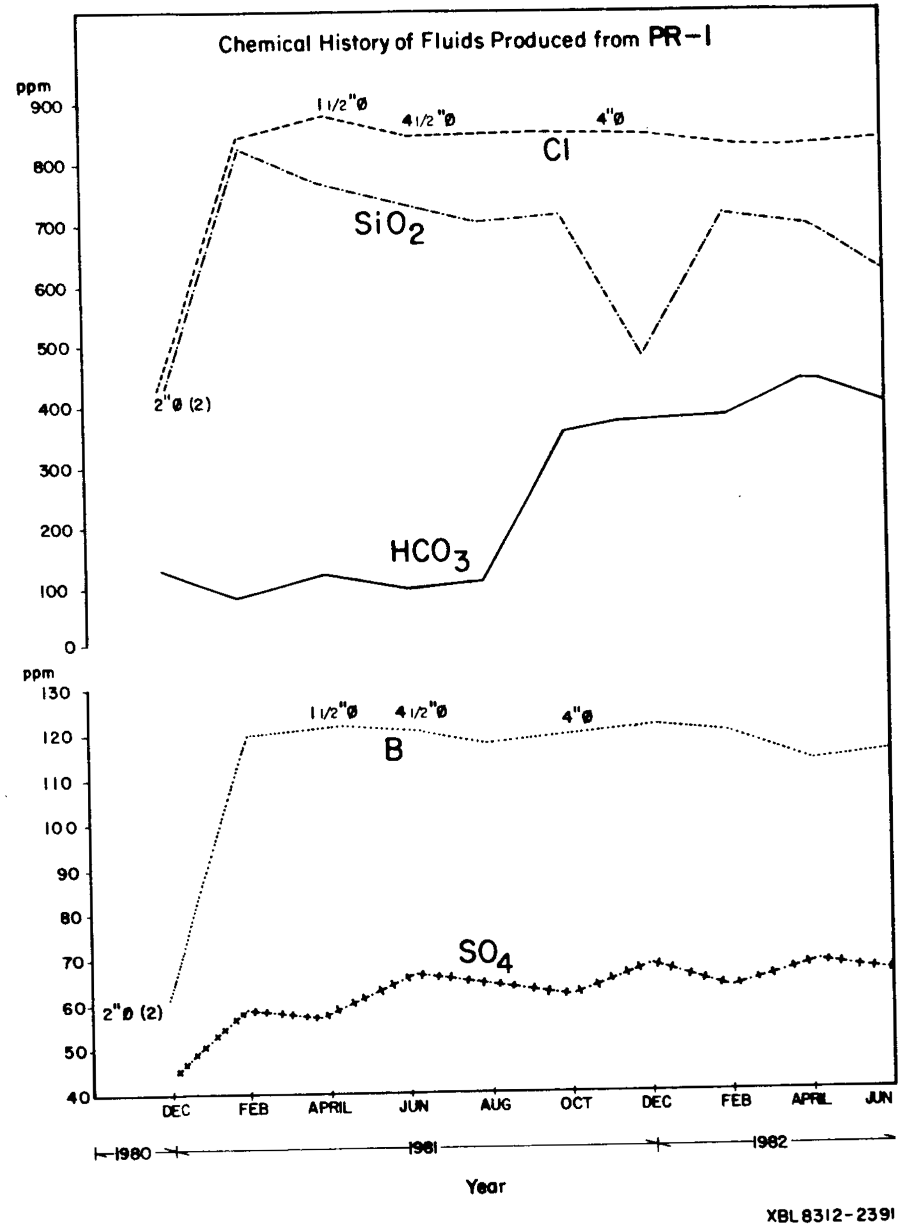

Figure 13. Well PR-1. Chemical history of produced fluids.