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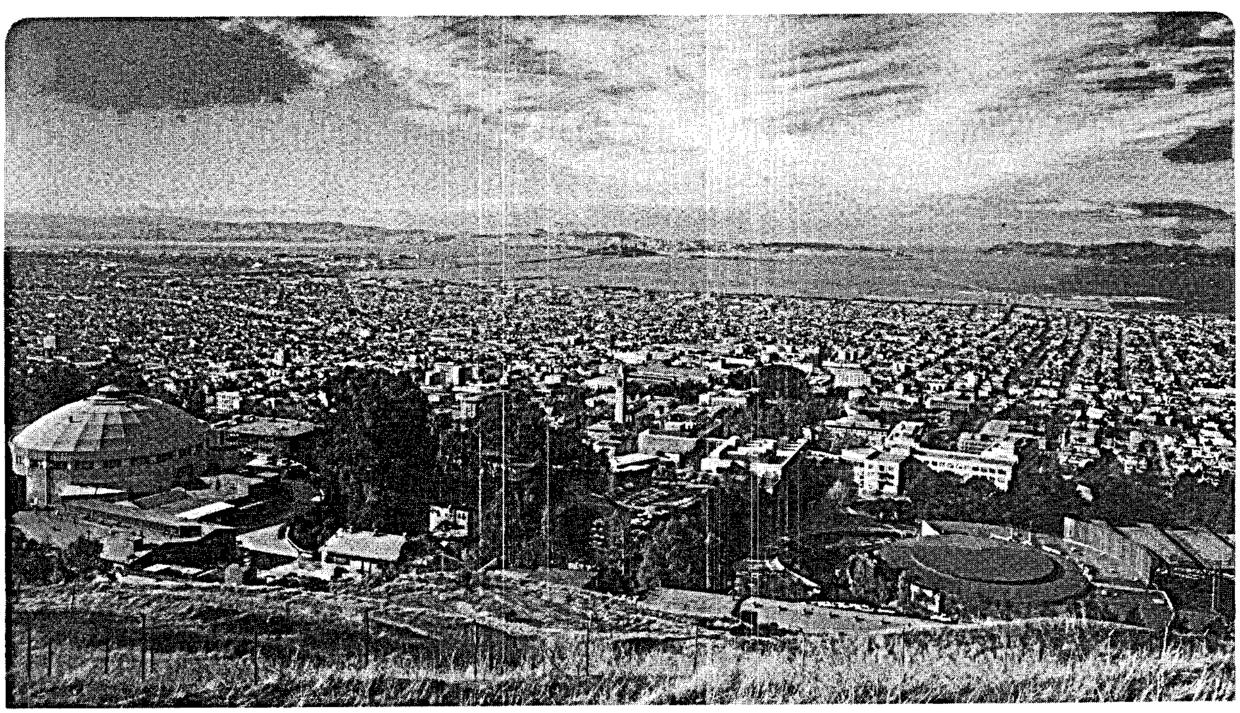

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IDENTIFICATION OF FLUID FLOW PATHS IN THE CERRO PRIETO GEOTHERMAL FIELD

Susan E. Halfman*, Marcelo J. Lippmann*, Rubén Zelwer*, John H. Howard**

*Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
**Lawrence Livermore National Laboratory, University of California, Livermore, California 94550

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ABSTRACT

A hydrogeologic model of the Cerro Prieto geothermal field has been developed based on geophysical and lithologic well logs, downhole temperature, and well completion data from about 90 deep wells. The hot brines seem to originate in the eastern part of the field, flowing in a westward direction and rising through gaps in the shaly layers which otherwise act as partial caprocks to the geothermal resource.

INTRODUCTION

The Cerro Prieto geothermal field, located about 20 miles south of the US-Mexico border in Baja California, Mexico (Figure 1), has approximately 100 wells, some as deep as 11,600 ft. These wells provide a vast amount of data for the study of the field's subsurface geology (Figure 2).

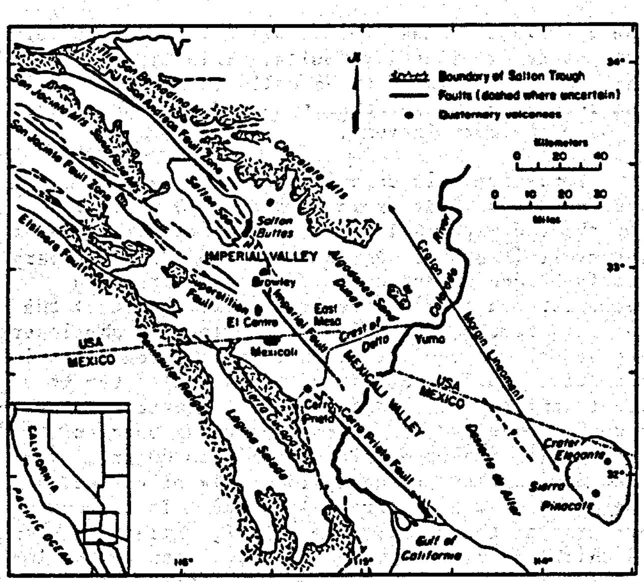

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Figure 1. Regional geology of the Salton Trough and location of the Cerro Prieto area.

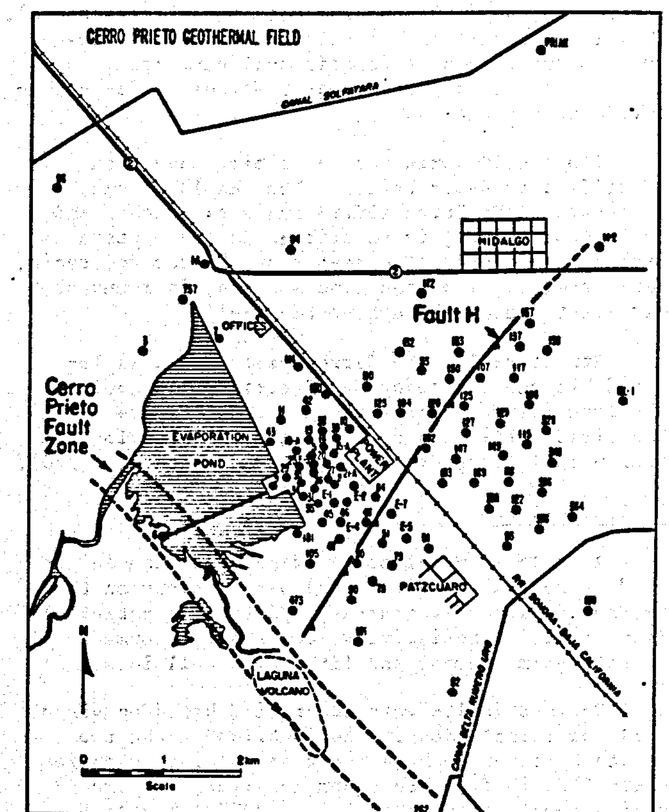

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Figure 2. Location of wells and of the two faults which have the greatest impact on geothermal fluid flow at Cerro Prieto.

Based mainly on the analysis of geophysical and lithologic well log data, a geologic model of the field has been developed. By integrating downhole temperature data and depth of producing intervals into this model, flow paths for the geothermal fluids have been identified. The results presented in this paper are consistent with those of other geological, geophysical, and geochemical studies carried out in this area (Lawrence Berkeley Laboratory, 1981).

GEOLOGICAL SETTING

The Cerro Prieto field is located in a sedimentary environment resulting from the southwesternly progradation of the Colorado Delta into the Salton Trough (Lyons and van de Kamp, 1980). In this area, the thick sedimentary column consists essentially of Pliocene and Pleistocene materials deposited in alluvial, deltaic, estuarine, and shallow marine environments (Ingle, 1982). The stratigraphy is dominated by intertonguing sandstone-shale sequences which have been grouped into two main units (Units A and B) by Puente and de la Peña (1978) based on drilling data. Essentially, Unit A consists of unconsolidated sediments, while Unit B consists of consolidated or indurated sediments. Elders et al. (1978) consider that the transition from unconsolidated to consolidated sediments may occur in different ways in different parts of the system (i.e., compaction, cementation, and methamorphic reactions). They suggest that the transitional contact between Units A and B is post-depositional cautioning on its use for stratigraphic correlations or for structural interpretations.

Two liquid-dominated reservoirs have been identified in Cerro Prieto. The shallower one, designated A by Prian (1979) and α by Sánchez and de la Peña (1981), is restricted to the western part of the field. The deeper and hotter reservoir, designated B (β) by the same authors, is found at different depths throughout the field.

Structurally, the Cerro Prieto field is located between two major NW-SE strike-slip faults, the Imperial and Cerro Prieto faults (Figure 1). The field itself has been postulated to be located over a pull-apart basin (e.g. Lomnitz et al., 1970).

GEOLOGIC MODEL

A geologic model of the field has been developed by Halfman et al. (1982) based mainly on the interpretation of gamma-ray, spontaneous potential, deep induction resistivity, compensated formation density gamma-gamma, and lithologic well logs.

Various faults were identified based on visual well log correlations. The location of the two faults believed to have the greatest impact on geothermal fluid flow are shown in Figure 2. The buried fault, tentatively named "H", exhibits a 1500-foot downthrow toward the southeast (Figures 3 and 4). It plays a significant role in providing a path for geothermal fluids to flow upward. The other major fault, the Cerro Prieto strike-slip fault, corresponds to the western boundary of the field and does not seem to carry fluids from great depths.

Based on the logs and depths of geothermal fluid production, the stratigraphic column has been subdivided into a number of formations having distinct lithologic and hydrologic characteristics. Figure 3 presents a northwest-southeast section across the eastern part of the field illustrating

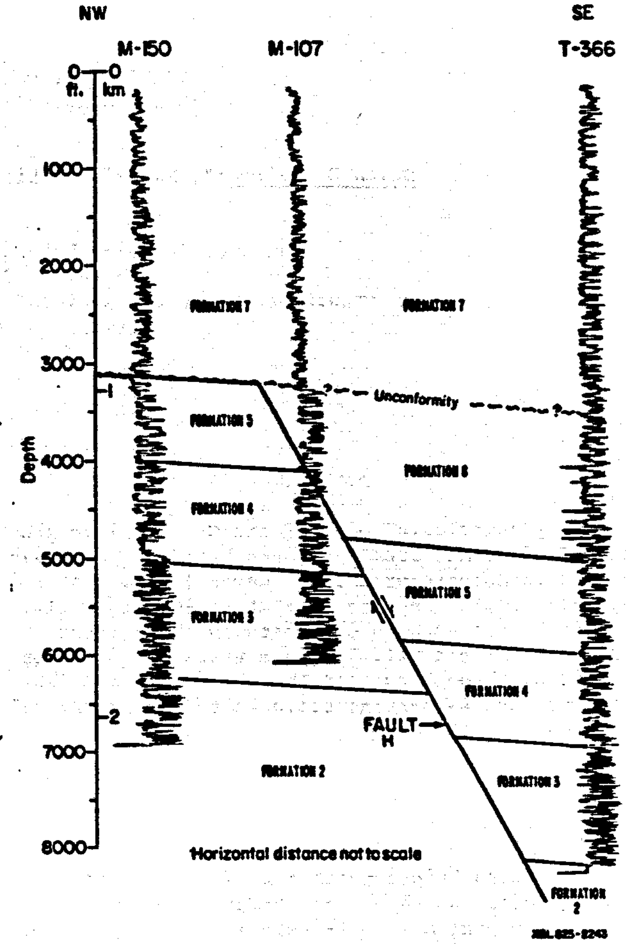

Figure 3. Simplified stratigraphy of the eastern part of the Cerro Prieto field. The traces correspond to gamma-ray logs.

the correlations used to establish the various formations and to identify faults. This figure shows the gamma-ray logs of three wells (M-150, M-107, and T-366), although other types of logs were also used in the correlations.

Formation 2 is comprised of some well-developed sandstone beds (some more than 70 ft thick) interbedded with shale beds and contains the deeper reservoir (B or β). Formation 3, comprised of very thinly-bedded sandstones and shales, acts as a local caprock to the lower reservoir. West of the railroad tracks, Formation 4 contains the shallower geothermal reservoir (A or α). In that region, this formation consists of rather thick shales (up to 100 ft thick) and sandstone-shale sequences. Formation 5, comprised of alternating sandstones and shale units (average thicknesses: 30-60 ft), overlies most of the producing intervals of the wells completed in the Reservoir A (or α). In the western part of the field, Formation 7, which has several thick shale units near its base, acts as the local caprock to the shallower reservoir.

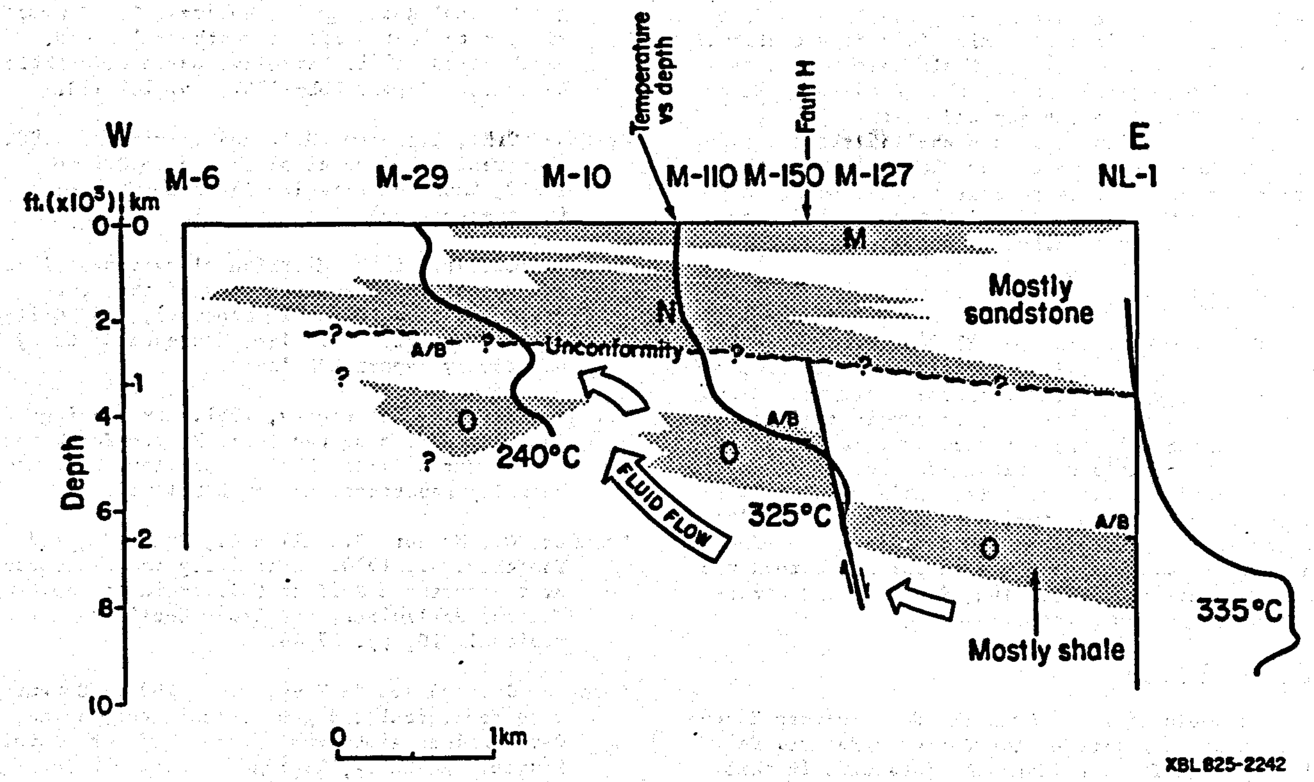

Figure 4. West-east cross-section of the Cerro Prieto field showing a schematic diagram of geothermal fluid flow through the field (indicated by arrows).

GEOTHERMAL FLUID PATHS

Figure 4 shows a west-east section across the entire field. It is a schematic version of one of the cross-sections presented by Lyons and van de Kamp (1980), who defined various lithofacies classes at Cerro Prieto using geophysical well log data.

The simplified lithology shown in Figure 4 was obtained by grouping these authors' lithofacies classes into mostly sandstone and mostly shale units, hereafter referred to as sand and shale units. Shale Unit O approximately correlates with Formations 3 and 4. Shale Units N and M are within Formation 7. Superimposed on this section are the temperature profiles for wells M-29, M-110, and NL-1 (from Bermejo et al., 1979, and personal communication, 1982), and the locations of the contact between Units A and B (A/B contact) for wells M-29, M-150, and NL-1. The producing intervals (not shown) are located within Shale Unit O in the vicinity of M-29. These intervals straddle and lie below the base of Unit O in the region east of M-10.

Some important features are noticeable in Figure 4: (1) The A/B contact is located at the top of Shale Unit O in wells M-150 and NL-1, and at the bottom of Shale Unit N in M-29, (2) The producing intervals are deepest near NL-1, and gradually become shallower toward the west, and (3) The temperature profiles show sudden increases in temperature gradients at depth near NL-1; these sharp inflections in the temperature profiles appear at shallower depths toward the west.

By comparing the temperature profiles at M-110 and NL-1 with the lithology, it can be noted that the increase in temperature gradients occur near the boundary between Shale Unit O and the overlying sand unit. On the other hand, in M-29 this increase is observed near the boundary between Shale Unit N and the underlying sand unit. The increase of thermal gradient suggests that the shale units must be barriers to convective heat transport, i.e., they essentially are acting as local caprocks. Furthermore, the maximum temperatures measured in these wells are highest near NL-1 (335°C), and decrease gradually toward the west (240°C, in M-29).

Based on the distribution of sand and shale units, location of producing intervals, and temperature profiles, a flow path for the geothermal fluids can be postulated. The fluids are believed to be heated at depth by a swarm of dikes intruded in the eastern portion of the field (W. Elders, personal communication, 1982). The fluids are thought to enter the field from that direction through the sands underlying Shale Unit O, then moving westward toward Fault H (the fluid flow path is indicated with arrows in Figure 4). As the fluids flow up the fault, encountering once again the bottom of Shale Unit O, they continue to flow westward below this shale unit. This flow continues until it reaches the gap in Shale Unit O between wells M-10 and M-110. There, the geothermal fluids flow upward through the gap and westward under Shale Unit N, which acts as a shallower local caprock. Eventually, some of the fluids leak to the surface through the Cerro Prieto fault zone, and the rest of the fluids mix with the colder waters which surround the geothermal anomaly.

CONCLUSIONS

The flow of geothermal fluids through the subsurface of the Cerro Prieto field is controlled by both stratigraphic and structural features. Many of the mineralogic, thermal, reservoir engineering, and geochemical characteristics of this geothermal system can be explained with reference to the hydrogeologic model described here. This model is a refinement of previous studies (e.g. Mercado, 1976; Elders et al., 1981). As new data is gathered and analyzed it will be possible to further extend the model to reflect the complex lithology and structure of the Cerro Prieto field.

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
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