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SUMMARY OF RECENT PROGRESS IN UNDERSTANDING THE CERRO PRIETO GEOTHERMAL FIELD, BAJA, CALIFORNIA, MEXICO

M. J. Lippmann and P. A. Witherspoon

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bу

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INTRODUCTION

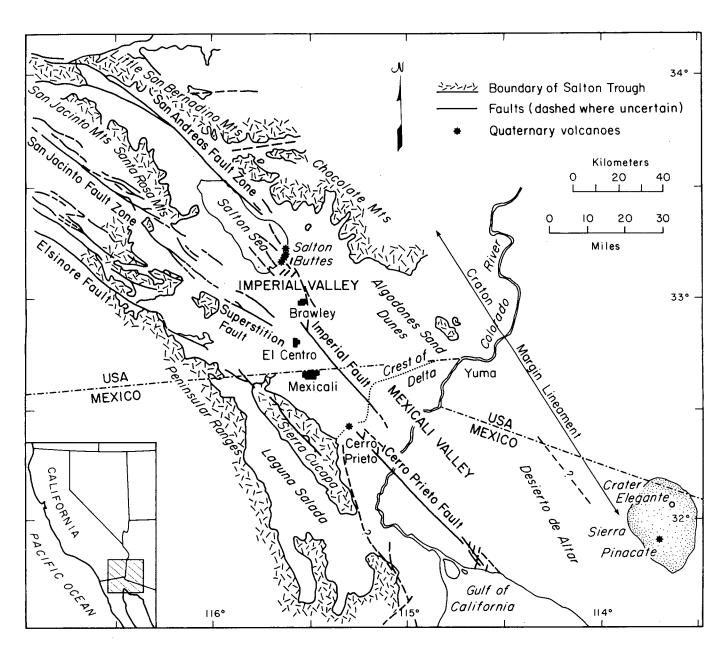
The Cerro Prieto geothermal field (Figure 1) is presently producing 150 MW of electric power. The latest plans of the Comisión Federal de Electricidad (CFE), which manages and operates the field, call for a total production of 660 MWe by 1984. Such large development plans are based on a comprehensive exploration effort which began in 1975.

About 75 deep wells have been completed in the area (Figure 2). The recently drilled wells in the eastern and southeastern parts of the field confirmed the existence of very hot reservoirs below 2000 m depth (Alonso et al., 1979). The intensive drilling program at Cerro Prieto is continuing with step-out wells in the eastern areas and exploration wells around the village of Hidalgo (Figure 2).

Lawrence Berkeley Laboratory (LBL), under the direction of the Division of Geothermal Energy of the U. S. Department of Energy, has been working with CFE in carrying out a Mexican-American Cooperative Project on Cerro Prieto. Results of on-going studies are discussed in the proceedings of the first two simposia on the Cerro Prieto field (Lawrence Berkeley Laboratory, 1979; Comisión Federal de Electricidad, 1980).

RESULTS FROM RECENT GEOLOGY AND GEOCHEMISTRY INVESTIGATIONS

A recent comprehensive geological and geophysical study by Lyons and van de Kamp (1980) showed that the subsurface stratigraphy at Cerro Prieto is characterized by complex vertical and lateral variations in lithofacies, typical of deltaic deposits. An example of the cross sections developed is given in Figure 3. The different lithofacies range from predominantly



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Figure 1. Location of Cerro Prieto within the Salton Trough.

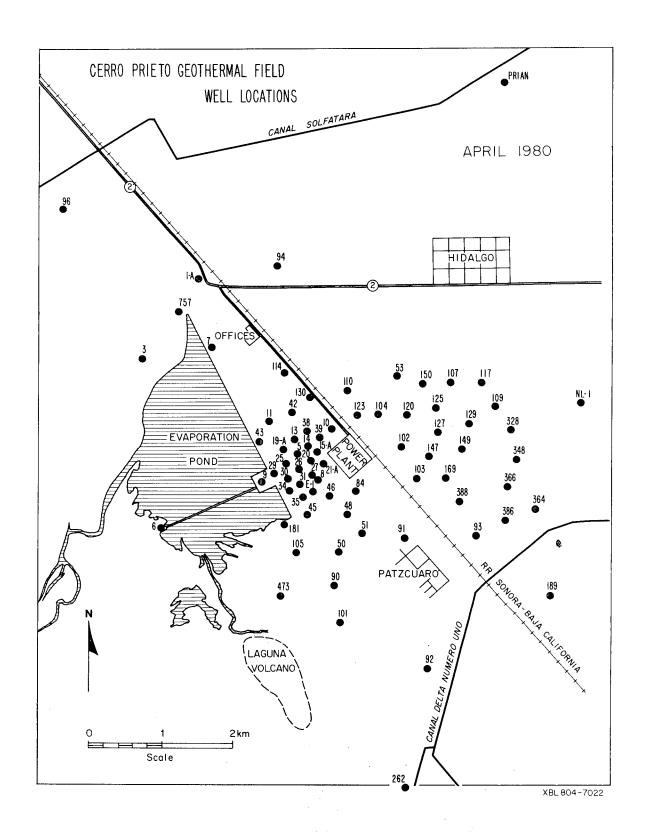


Figure 2. Geothermal well locations at Cerro Prieto, as of April 1980.

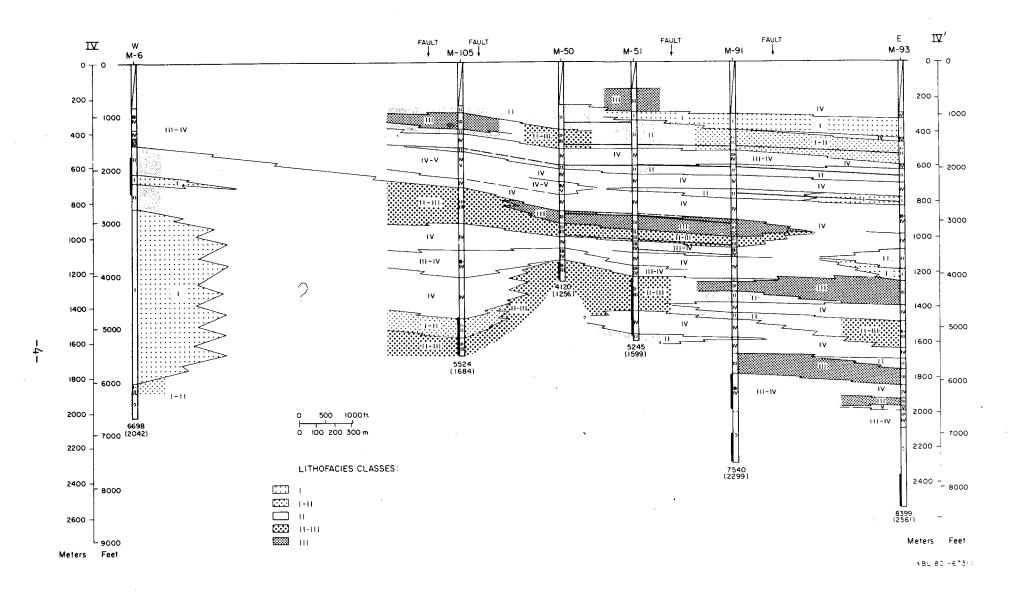


Figure 3. West-east stratigraphic cross section at Cerro Prieto; location shown in Fig. 4. (from Lyons and van de Kamp, 1980).

sand (I) to predominantly silt/shale (V). Lyons and van de Kamp have concluded that the geothermal production zone is not a uniform reservoir layer overlain by a laterally continuous seal of low permeability strata. The deeper part of the section in the main producing area on Figure 3, including the productive intervals, represents lower delta plain deposits of the ancestral Colorado river. A generalized map of the depositional environments for the deeper part of the section is given in Figure 4.

The structural picture of Cerro Prieto is complex. Lyons and van de Kamp (1980) have suggested the presence of north-south and north-northeast to south-southeast striking faults in addition to the northeast-southwest and northwest-southeast faults established by earlier workers. According to their interpretations, the faulting includes: (a) old faults, (b) old faults that have been reactivated, and (c) new faults. A map developed during a recent internal CFE/LBL meeting showing a simplified version of the present fault structures is given in Figure 5.

The Cerro Prieto Fault shown on Figure 5 is the local expression of a northwest-southeast fault zone that is traceable from the Gulf of California to the Cerro Prieto volcano. It is believed to be a boundary fault to the productive reservoir, rather than a discontinuity that carries fluid (S. Vonder Haar, personal commun.). This is partly based on the generalization that strike-slip faults do not account for significant fluid flow compared to normal or reversed faults. The Volcano fault system, trending northeast-southwest, is considered to have three main fault zones (Delta, Pátzcuaro, and Hidalgo). This system of fractures is generally believed to act as a series of conduits for fluid flow especially where it intersects the northwest-southeast Cerro Prieto fault zone.

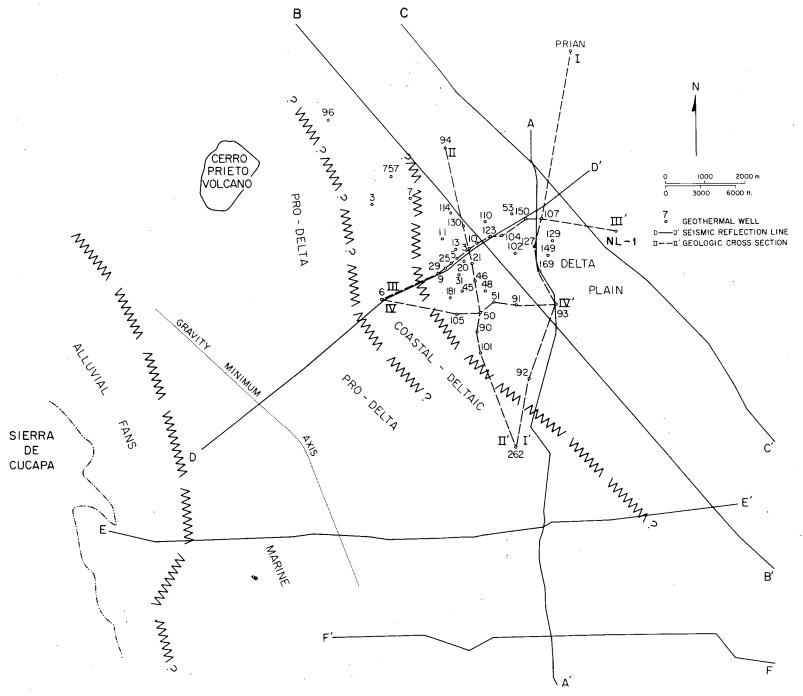


Figure 4. Generalized map of depositional environments for the deeper part of the section at Cerro Prieto (from Lyons and van de Kamp, 1980).

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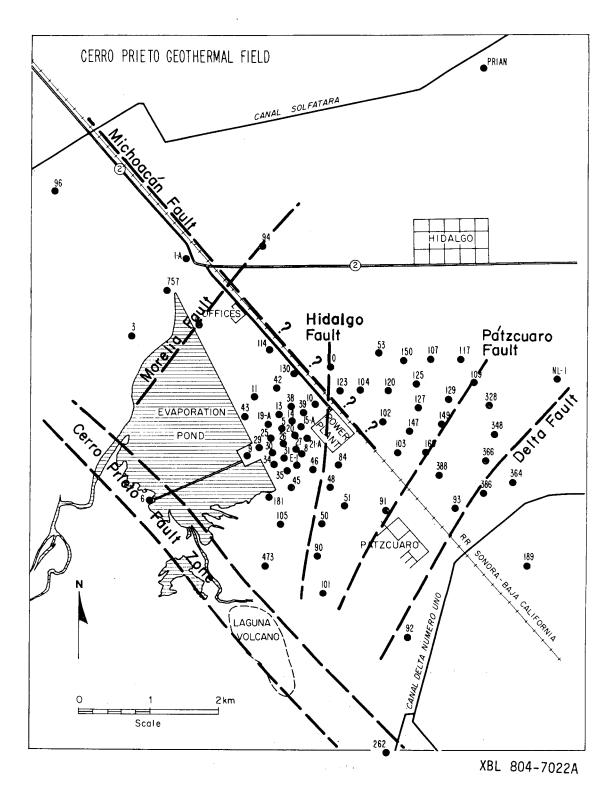


Figure 5. A simplified fault map of Cerro Prieto.

Other interesting results of the Lyons and van de Kamp study are that (a) the geothermal production intervals generally straddle or underlie the top of the high-resistivity, high-density shales that characterize the indurated hydrothermal altered zone described by Elders et al. (1980); and (b) sandstones in the hydrothermal alteration zone commonly have good to excellent porosities (15% to 35% or higher) resulting from the solution of unstable grains and carbonate cement. Lyons and van de Kamp consider that while fractures may be an important contributor to reservoir permeability locally, secondary matrix porosity and permeability are more important volumetrically in the Cerro Prieto reservoirs. On the other hand, Noble and Vonder Haar (1980) suggest that hydrothermally precipitated clay minerals, readily observable under a scanning electron microscope, seem to clog pore throats and reduce permeabilities even though secondary matrix porosities approach 40%.

A series of investigations on the geochemical environment at Cerro Prieto have been carried out in an effort to understand the behavior of the reservoir and circulation system under the influence of significant fluid withdrawal. According to Truesdell (1979) widespread boiling occurred in the Cerro Prieto reservoir soon after the start of power production in 1973. In mid-1975 the drawdown was so great that lower-temperature, lower-chloride waters broke through from a shallower aquifer. This breakthrough reversed the steep declines in water levels of shut-in wells, decreased the chloride content of the reservoir brines in the central part of the field, and increased substantially the silica concentrations as boiling zones collapsed and near-well temperatures rose.

Based on chemical and isotopic studies of the Cerro Prieto brines,

Truesdell et al. (1979) have concluded that the fluids derive from a

mixture of partially evaporated sea water and Colorado River waters, which

were extensively altered compositionally by high-temperature reactions

involving the reservoir rocks. The hot fluids rising through faults in

the eastern part of the field are believed to move from east-southeast to

west-northwest at some depth while cold water from the Colorado River is

recharging the reservoir from a northeast direction.

RESULTS FROM WELL TEST ANALYSES

In gathering reservoir data for investigations of productive capacity and the development of numerical models, it has been necessary to carry out a series of well tests in the field. A number of two-rate flow tests and interference tests have been carried out by CFE and LBL since 1977. Interpretation of these tests has in some cases been complicated by the two-phase conditions existing in the wellbores and by the tectonism of the area. Short, two-rate flow tests are usually easy to analyze because they involve a relatively small region of the reservoir around the well being tested. Because of the complex geology of the area, data from interference tests tend to show the presence of boundaries and lithofacies changes, making it more difficult to interpret the results.

The tests completed so far indicate that the intrinsic permeability of the reservoir is on the order of tens of millidarcies. From two-rate flow tests in wells M-21A and M-25, Rivera and Ramey (1977) reported kh values between 1950 and 2860 md-m (6400 and 9380 md-ft). Abril and Molinar (1980) obtained a kh value of 4362 md-m (14,310 md-ft) for similar tests in well M-102.

They also report an intrinsic permeability of 90 md for an interference test conducted between wells M-102 and M-103.

A long interference test involving four producing wells (M-50, M-51, M-90 and M-91) with M-101 as the observation well was made by Schroeder et al. (1979) in the southern part of the field. Figure 6 compares smoothed pressure data observed in M-101 with production-well flow rates, which varied considerably. It has been possible to analyze these data using a new mathematical code developed at LBL (McEdwards, 1979) that can handle multirate, multiwell flow rates. Figure 7 shows the computer matched results imposed on actual data. In analyzing the results of this complex interference test, we could not easily match the early observation well drawdowns caused by the production of well M-91. Data for times exceeding 15,000 minutes (>10 days) were readily analyzable. However, flow rates at M-91 could not be ignored at late times, suggesting possible effects of partial penetration, layering, and so on. Results for the mobility-thickness product (kh/μ) are 4.5 x 10^5 md-m/cp, and for storativity (ϕ ch), 7.0 x 10⁻³ m/psi. Assuming a reservoir thickness (h) of 1000 m, the average permeability value becomes 45 md.

CONCLUSIONS

Geological and geophysical studies indicate that the Cerro Prieto reservoir is quite heterogeneous due to complex lithofacies fault structures, and hydrothermal alteration. Geochemical investigations have provided clues on the origin of the geothermal fluids, their recharge paths and on the reservoir processes accompanying the exploitation of the field. Well tests have yielded information on the permeability of the reservoir, and future tests will establish the permeability variation throughout the area.

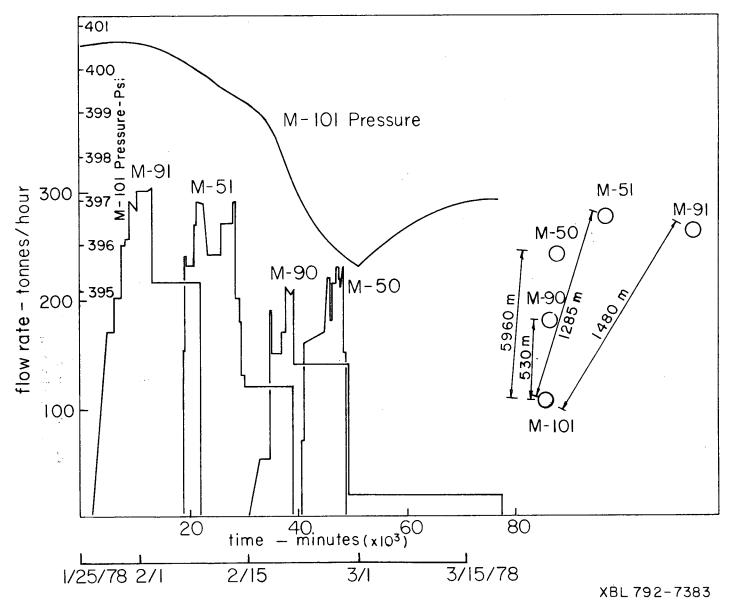


Figure 6. Interference test in the southern region of Cerro Prieto using M-101 as observation well and M-50, M-51, M-90, and M-91 as production wells.

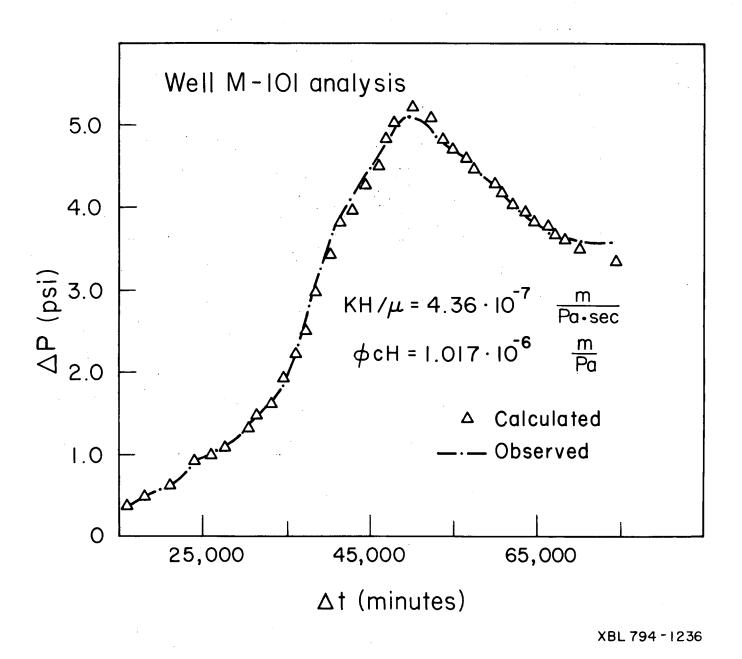


Figure 7. Interference test at Cerro Prieto showing measured versus computed drawdowns in observation well M-101.

This recently acquired knowledge will permit a more realistic numerical modeling of the field's behavior as its exploitation continues. To date, the simulations reported in the symposia on Cerro Prieto have only dealt with simplified models of this complex geothermal system.

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