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Numerical Study of the Effects of Brine Injection on the CP1 Production Area of Cerro Prieto

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The present study is being conducted, under a cooperative agreement between the United States Department of Energy (DOE) and Mexico's Comisión Federal de Electricidad (CFE), to analyze how brine injection could affect the shallow (α) and deep (β) reservoirs of the CP1 production area of the Cerro Prieto geothermal field, Baja California, Mexico. Since the beginning of the exploitation of Cerro Prieto in 1973, one of the most important operational problems that CFE has had to face was the handling of the waste brine (Hiriart and Gutiérrez Puente, 1992). To date, most of the brine is discarded by means of evaporation ponds that cover an area of 18.6 km^2 (4600 acres) (Figure 1). An infiltration area west of the ponds is used during the winter, when the evaporation rate is significantly lower. Recently, CFE started a series of cold brine (approximately at 20°C) injection tests, using brine from the evaporation ponds. The objectives of these tests were to monitor the reservoir's response to injection and to test the injectivity of different areas of CP1 in the western part of the field. CFE's eventual goal is to inject all the separated brine back into the system, to eliminate its surface disposal, and, at the same time, maintain pressure in the reservoir.

The main objective of the present study is to use numerical simulation to help CFE define the possible location(s) for injection, minimizing possible negative effects and maximizing reservoir pressure. Of special interest is determining how brine injection will affect the CP1 zone in which wells are currently producing a steam and brine mixture. A numerical model of CP1 was built using data provided by CFE. The computational grid was defined on the basis of the geological model of the field (faults and structural features of the gray shale and the basement, as provided by CFE), the location and completion of the production and injection wells (see Figure 2), and interpretation of geochemical data (Truesdell et al., 1989). Figure 1 shows the location of the simulation grid with respect to the different Cerro Prieto production areas. In the vertical direction the model extends from the surface to 5000 m depth and is divided into six layers. All the layers have the same areal distribution and have 235 grid elements (Figure 3), except layer 5, which has 47 additional blocks in the northeast, simulating the volume of the CP2, CP3, and CP4 areas. The numerical model has a total of 1457 elements and was developed as a single-porosity model. The simulation

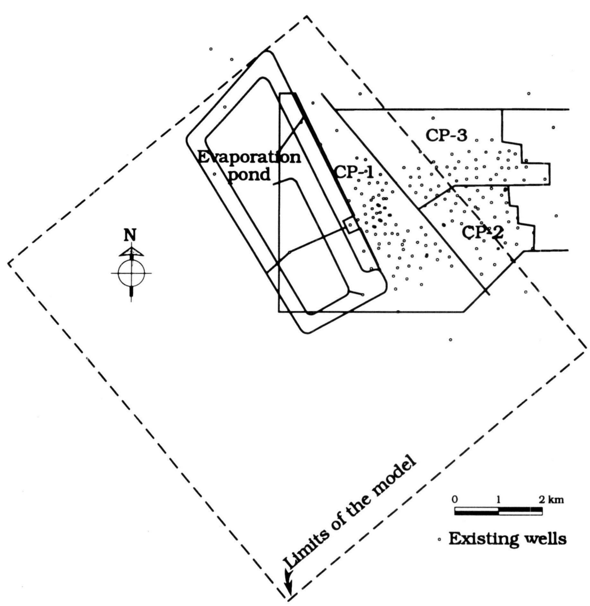

Figure 1. Location of the limits of the model with respect to the Cerro Prieto production areas. [XBL 935-801]

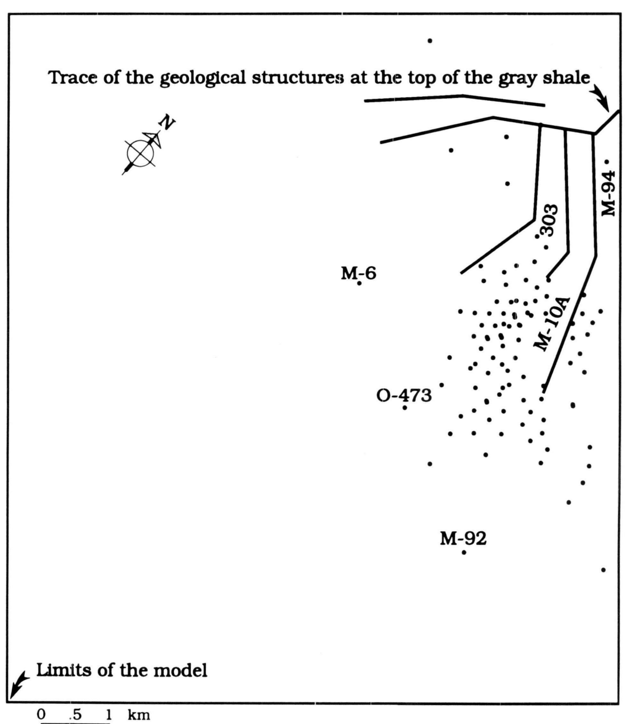

Figure 2. Well locations and geological structures within the modeled area. [XBL 935-802]

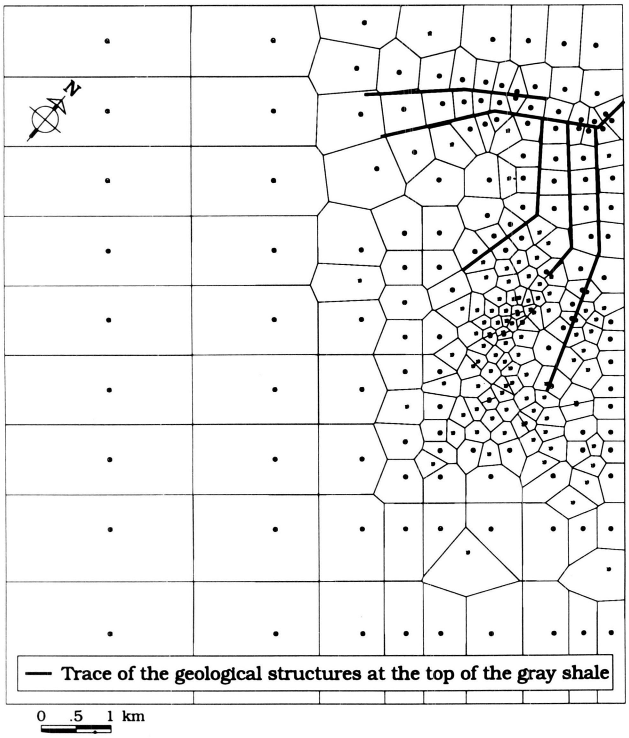

Figure 3. Areal distribution of the grid used in the numerical model to study the effects of brine injection in CP1. [XBL 935-803]

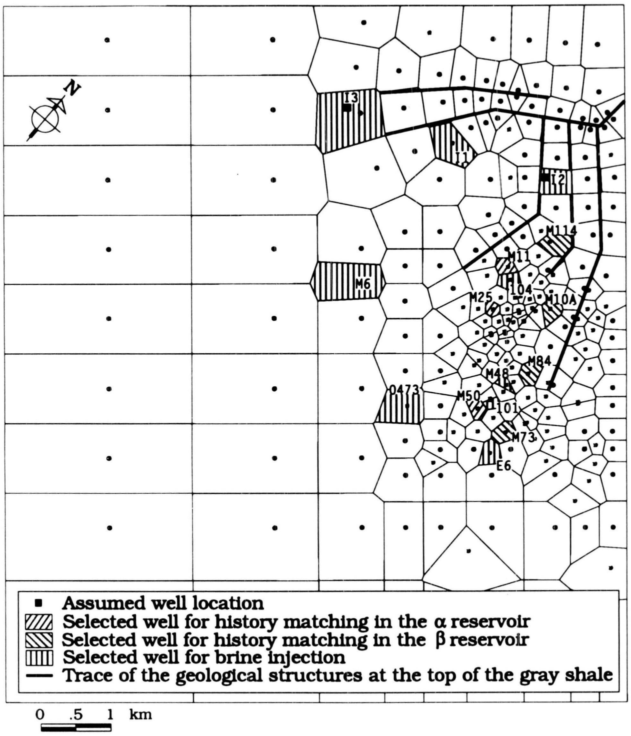

Figure 4. Location of the wells selected for production-history matching and to study brine injection. [XBL 935-804]

runs are being done with the TOUGH2 simulator developed at LBL (Pruess, 1991) and an improved matrix solver implemented by Bullivant et al. (1991).

The calibration of the model is being conducted in three stages. The first stage consists of the reproduction, with the model, of the undisturbed (initial-state) temperatures and pressures. The second stage will be achieved when the model matches (1) the production enthalpy history from April of 1973 to the end of 1985 and (2) the 1985 downhole measured pressures. The third stage will include the matching of the production data from 1986 (year that CP2 and CP3 started operating) to the end of 1991. Not all the active wells in CP1 were used for the history match; instead, seven wells with typical production behavior from the different CP1 zones were chosen. The selected wells with completions in the shallow reservoir (α) are M-11, M-25, and M-50; those completed in the deep reservoir (β) are M-10A, M-73, M-84, and M-114. Figure 4 shows the location of these wells in the computational grid. After the third calibration stage is accomplished, the model is used as a prediction tool to determine the behavior of the CP1 area under various assumed production/injection scenarios.

Personnel of CFE and LBL defined four scenarios to analyze the CP1 area response to 5 years of brine injection, starting on January 1, 1992.

Scenario I. Base case. Wells will continue producing at a rate equal to that measured at the end of 1991, when the average field production was 5459 t/h of steam and 6394 t/h of separated brine. No injection will be considered.

Scenario II. Inject 3500 t/h of 20°C brine evenly distributed between injection wells M-48, 101, 104, E-6, O-473, and M-6. Production is the same as for Scenario I. Injection well locations are shown in Figure 4.

Scenario III. Inject 3500 t/h of 20°C brine using six wells. Wells I-1, I-2, and I-3 will be receiving 800 t/h each, and the rest will be evenly distributed between wells E-6, O-473, and M-6. Production is the same as for Scenario I.

Scenario IV. Inject 3500 t/h of brine evenly distributed between wells M-48, 101, 104, E-6, O-473, and M-6. The first four wells will be injecting brine at 150°C and the other two at 20°C. Production is the same as for Scenario I.

To date, all stages of calibration and prediction are partially completed. At this point, these different stages are carried out sequentially from initial state to the end of the scenarios, changing the fitting parameters for the different simulation runs according to the results of previous runs.

The matching procedure is finished when the "best" match to the measured data is achieved. Preliminary results obtained from the prediction runs show that after injecting 3500 t/h of brine for 5 years, the temperature and pressure changes around the injection areas are not significant.

RECOMMENDATIONS

If a program of brine injection similar to those proposed in Scenarios II to IV is carried out in CP1, it is recommended that a temperature and pressure monitoring program be established using observation wells around the injection areas. Data collected from the observation wells should be used as feedback to the simulation model. The model could be a useful tool to detect and/or to predict trouble zones in the field. We consider that the analyses of the data from the observation wells and the simulation model will be a very useful in the design of the large-scale brine injection operations planned for Cerro Prieto.

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Slit-Island Fractal Analysis of Single Fracture Aperture Patterns

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The character of fracture openings (apertures) is often one of the primary factors controlling fluid flow in the fracture. In particular, the shape, distribution, and connectivity of contact areas and flow channels can affect the relative permeability of wetting and nonwetting fluid phases in unsaturated systems. We used three methods of fractal analysis (the slit-island, the divider, and the variogram) as well as statistical and geostatistical analysis to characterize the geometry of measured fracture apertures obtained from two fractured rock specimens (Cox and Wang, 1993). One of these is a fracture in a granitic rock of homogeneous lithology; the other is a fracture in a specimen obtained from a highly altered fault zone containing striations and slickensides.

FRACTURE APERTURE DATA

Fracture aperture measurements of a fractured rock specimen sampled from a fault near Dixie Valley, Nevada, were obtained by three nondestructive fracture measurement techniques. The fracture aperture pattern was measured by profilometry (Power, 1989), by light transmission through translucent silicone casts (Cox et al., 1990), and by light transmission through dyed fluid in epoxy replicas of the rock (Persoff and Pruess, 1993). We examined the Dixie Valley fracture aperture as measured by the dyed-fluid method (Persoff and Pruess, 1993) and compared its aperture topography with that of a fracture in a specimen of Stripa granite (Persoff et al., 1991) measured by the same technique. Using this same approach, we compared the variability of the three Dixie Valley data sets measured by different techniques with the aim of distinguishing intrinsic features from experimental artifacts.

FRACTAL ANALYSIS BY THE SLIT-ISLAND METHOD

Fractal geometry offers an approach to geometric description of irregular geometric patterns (Mandelbrot, 1982). The fractal dimension of topographic surfaces measures the rate of change in the total length of contours or profiles as a function of the rate of change of a measurement interval. The fractal analysis of surfaces can be approached by at least seven different measurement methods (Cox and Wang, 1992), including the divider, variogram, and slit-island methods.

The slit-island method was first introduced by Mandelbrot et al. (1984), who used it to determine the fractal dimension of steel fractures. We applied this technique numerically to topographic surfaces (Figure 1) of