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WELL LOG ANALYSIS APPLIED TO CERRO PRIETO GEOTHERMAL FIELD

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Introduction :

The Cerro Prieto Geothermal Field is a liquid-dominated geothermal system located 30 km southeast of Mexicali Baja, California, Mexico, in the Mexicali Valley. Although some wells were drilled and completed in the late 60's, it was April, 1973, when the geothermal power plant began operating with a capacity of 75 MW of electric power. Presently, the power plant installed capacity is 150 MW but this amount is expected to increase as further field development is planned to take place in the coming years. A number of questions are being presently asked as this field development continues. What will the deliverability of this geothermal field be in relation to planned installations? Will reinjection be required to supplement aquifer recharge? What will be the reservoir life and ultimate recovery?

This concern has resulted in a joint project, where Comision Federal De Electricidad, Instituto De Investigaciones Electricas and INTERCOMP Resource Development and Engineering, Inc., of Houston, Texas are presently involved in performing reservoir simulation studies on the Cerro Prieto Field.

An integral part of this project is the analysis of geophysical well logs to determine basic reservoir parameters. There are three primary sources of data on the petrophysical properties of a reservoir: core analysis, well tests and well logs. Core analysis data are limited because of the expenses involved in obtaining the core samples and performing the analysis. Well test analysis provide reservoir properties averaged over a large volume and therefore is not detailed. Well log analysis then, is the prime means of obtaining detailed data from the reservoir. A distribution of material parameters can be obtained from this analysis and the reservoir can be better defined for simulation purposes.

Data Gathering. In late 1976, as a result of the DOE/CFE Cooperative Agreement, The Lawrence Berkeley Laboratory (LBL) of the University of California began a systematic digitization of selected geophysical logs in order to permit computer analysis of the Cerro Prieto well logs. Selected wells throughout the field were chosen for this study. Before any computer techniques were applied, the digitized well logs were visually compared with the original blue prints to make sure that only reliable data could be used in making any interpretation. Special care was taken for any possible depth shift on logs run in each well and when such depth shift was present, a correction was made for this effect.

Selecting the Reservoir Interval of Study. The structural geology of the Cerro Prieto Field has been presented in several proceedings related to this field and it is well known. The formation is of sedimentary type with alternating shale and sand-stone layers resting on a highly fractured granitic basement. There are some structural interpretations of this field based on temperature and electrical logs in the literature. For this study, basically the lithologic column presented by Abril and Noble in 1978[1] was selected. Figure 1 presents a typical field cross-section resulting from that work and Figure 2 shows its location on the field. From this lithologic column, intervals L_2 and Reservoir **A** were of special interest for the following reasons: a) for simulation studies, these zones will be of interest because most of the existing wells are completed here and consequently, all reservoir data (production data, well tests) come from these zones, and b) although the formation temperature begins to increase rapidly in Zone N, this zone presents a high content of carbonate ions in solution resulting in many well completion and scaling problems.

Determination of Effective Porosity. The computer program used for all calculations was INTERCOMP's Log Analysis Program. This program permits the use of petrophysical relationships whether they be standard industry accepted equations or derived empirical relationships. This program is full explained in Reference **11.**

For a clean sandstone lithology, the density log is usually the most reliable porosity device. When shale is present, a correction has to be applied to density log readings for determining effective porosity. From the density log:

$$\phi_D = \frac{\rho_{ma} - \rho}{\rho_{ma} - \rho_f}$$

ρ = Density Log Reading

ρ_{ma} = Matrix Density

ρ_f = Formation Fluid Density

and:

$$\phi_e = \phi_D - V_{sh}\,\phi_{Dsh}$$

where:

ϕ_e = Effective Porosity

ϕ_D = Porosity from Density Log

V_{sh} = Shale Volume

ϕ_{Dsh} = Shale Porosity

The shale volume can be obtained from gamma ray or Sp logs.

From the gamma ray log:

$$V_{sh} = \frac{GR - GR_{min}}{GR_{max} - GR_{min}}$$

From the SP log:

$$V_{sh} = 1 - \left(\frac{Sp - Sp_{min}}{Sp_{max} - Sp_{min}}\right)$$

In order to obtain maximum and minimum log values, the gamma ray and Sp log responses were histogrammed in each interval. Figure 3 presents a typical histogram for well M27. It is well known that both logs tend to over estimate shale volume. In our case, shale volume was evaluated from both logs and the minimum value was used for the effective porosity determinations. The exception to this was the case where the baseline drifts in the self potential log were apparent and this log was not used or when just one of these logs was run in a particular well.

An average effective porosity was obtained by arithmetically averaging the incremental determined porosity in each zone. Porosity values greater than 40% were disgarded on the averaging procedure. Figure 4 presents the obtained effective porosity values for both intervals. At this time, no consistent core data was available to verify the reliability of the obtained porosity data. Core samples from selected wells are being presently analyzed at IIE Petrophysical Laboratory. As this is done, reservoir permeability, another basic reservoir parameter, will be determined by means of some sort of porosity-permeability transform.

Evaluation of Water Salinity. The methods used to determine water salinity from well logs are reported and discussed elsewhere in the literature [3,9] and will not be reviewed here. Three of those methods that can be applied to the Cerro Prieto Field were selected for this purpose. They are different in the way the formation water resistivity (R_w) is determined. A brief description is as follows:

Method I - Requires only the spontaneous potential log. So at any depth:

$$R_w = (R_{mf})^{10(SSP/K)}$$

where:

K = $61 + 0.133\,T$, T in °F

R_{mf} = Mud Filtrate Resistivity (from log headings and temperature log)

SSP = Static Spontaneous Potential Value

Method II - Evaluates R_w using an electrical log and a porosity log. At any depth:

$$R_w = \frac{R_t\,\phi_e^{\,m}}{a}$$

m = Cementation Factor

a = Constant in Archie's Formula $F = a\phi^{-m}$

R_t = True Formation Resistivity

Method III - Uses a Simandeoux water saturation equation (total shale equation)[14]. In this case, water saturation is assumed to be 100% and the only remaining unknown is the formation water resistivity, R_w. That is:

$$R_w = \frac{\phi_e^{\,m}}{a(1-Vsh)\left(\frac{1}{Rt} - \frac{Vsh}{Rsh}\right)}$$

where:

ϕ_e, m, a, V_{sh}, R_t are defined before in this paper.

R_{sh} = Shale Resistivity.

After R_w is obtained from any of the three methods described above, total disolved solids (water salinity) can be found from a correlation for Na Cl solutions reported in the literature[7].

$$Na\,Cl\ eq = 10^x$$

$$x = \frac{3.562 - \log(R_{w75} - 0.0123)}{0.955}$$

and:

$$R_{w75} = R_{wT}\,\frac{T + 6.77}{(75 + 6.77)}\ ,\quad T \text{ in } ^{o}F$$

Some facts have been taken into account in evaluating the resistivity terms. It is a well known effect that both the invasion of drilling mud into the formation and temperature measurements or calculations of true formation resistivity (R_t) and some authors [5] have proposed various methods to overcome this problem. In our case, when possible, R_t was corrected for mud invasion effects according to the method presented by Bateman et al. (1978). Regarding temperature effects, this is not a serious problem as long as enough data is available to determine true or initial formation temperature. If the temperature profile deviates radically from a linear relationship, this profile must be considered. Although some methods for determining static reservoir temperature during drilling operations, have been presented in the literature[6,8,13], they could not be used because there was not enough required drilling data for this purpose. Instead, the stabilized shut-in well temperature profile obtained during the observation period was selected as an approximation to true formation temperature. For some fractured geothermal fields this temperature profile is not representative of reservoir temperature because of the existence of internal flows within the well[10] but Cerro Prieto is of sedimentary type field and it was suggested recently[4] that this phenomenon was unusual in this field,

The water salinities determined from these three methods were compared with laboratory data[12] and the results are shown in Figure 5. As we can observe, water salinities evaluated from the self potential log (Method I) and those evaluated using the Simandeoux's Equation (Method III) were lower than the laboratory reported data. Water salinities calculated from resistivity logs and density logs (Method II) were closer to the actual water salinity values. This has been found to be the case in other geothermal fields[5].

final Remarks

The obtained information will be of great help for the planned reservoir simulation studies of this geothermal field. As more wells are being analyzed, more data regarding reservoir parameters will be known. At the present time, some wells are being drilled and completed into the deeper reservoir B interval. That portion of the reservoir will also be analyzed and included in the simulation study.

Acknowledgements

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FIGURE 1 - TYPICAL FIELD CROSS-SECTION (FROM ABRIL AND NOBLE, 1978)

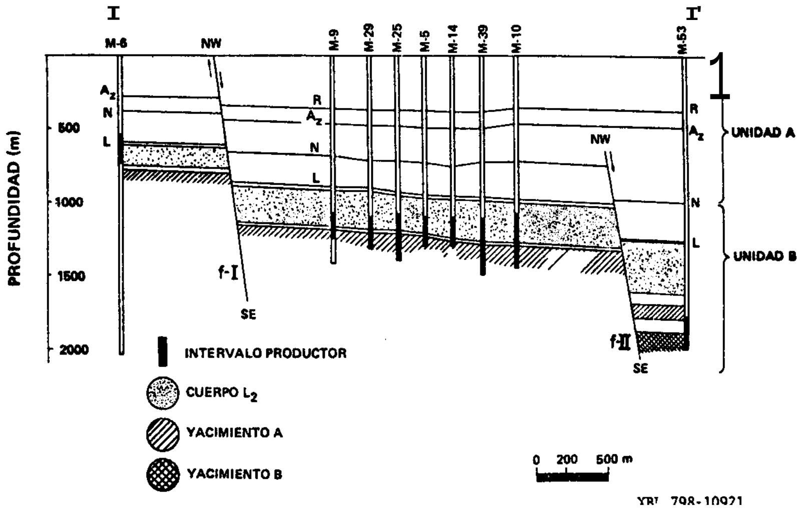

FIGURE 2 - LOCATION OF THE FIELD
CROSS-SECTIONS (FROM ABRIL AND NOBLE, 1978)

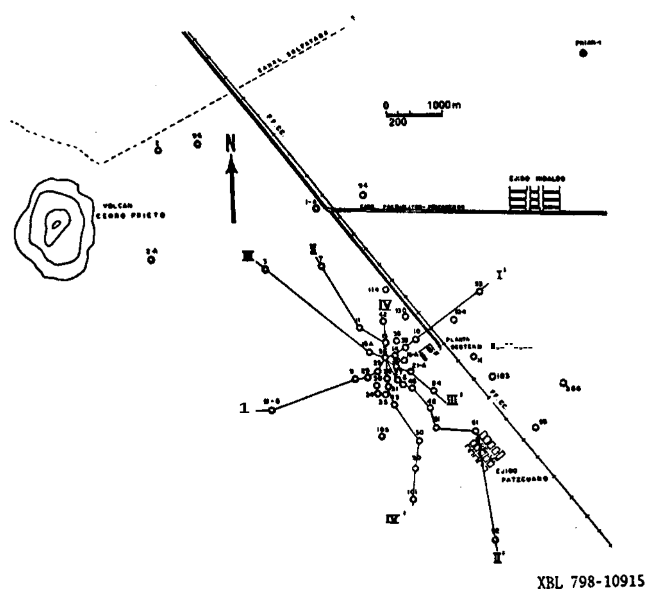

FIGURE 3 - GAMMA LOG RESPONSE
HISTOGRAM FOR WELL M27

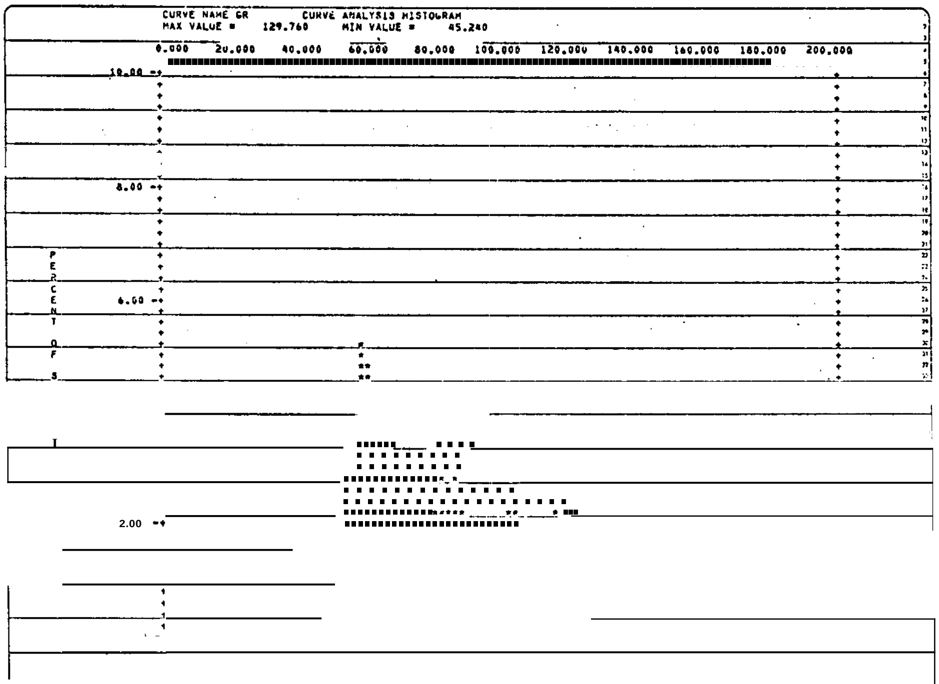

FIGURE 4 - AVERAGE POROSITY VALUES FOR INTERVALS L_2 AND A

WELL	ZONE	INTERVAL (ft)	POROSITY (%)
M19A	L_2	2900 - 3750	19.7
	A	3800 - 4270	16.0
M25	L_2	2900 - 3800	20.2
	A	3850 - 4580	12.0
M27	L_2	3100 - 4000	19.7
	A	4050 - 4210	13.2
M29	L_2	3450 - 3700	15.7
	A	3750 - 4180	13.3
M43	L_2	2930 - 3730	19.0
	A	3800 - 4090	15.4
M45	L_2	3100 - 3860	16.4
	A	3900 - 4570	14.5
M46	L_2	3000 - 3800	15.9
	A	3850 - 4650	11.5
M50	L_2	3050 - 3900	16.5
	A	3950 - 4120	17.0
M101	L_2	3590 - 4350	16.5
	A	—	
M102	L_2	3900 - 5350	19.1
	A	5500 - 6300	12.9
M107	L_2	4500 - 6060	17.1
	A	—	—

FIGURE 5 - AVERAGE WATER SALINITY DATA AS

PPM NaCL equiv CALCULATED FROM THREE

DIFFERENT METHODS

WELL	INTERVAL (ft)	*WATER SALINITY (PPM) METHOD I	METHOD II	METHOD III	LABORATORY DATA
M19A	3600-4240	1650	10465	6013	13812
M25	3580-4590	4266	13499	6504	15054
M27	3600 -4240	1958	9306	4840	11794
M29	3608-4250	1151	17037	9664	13044
M43	3772-4100	3127	14617	8512	13076
M45	3900-4120	730	10806	4477	11060
M46	3930- 4640	1278	10885	5650	10113
M50	3750-4120	1348	9329	3002	13278
M53	6050-6550	—	15225	8793	14446

*Salinity at reservoir conditions