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Gas equilibria in Cerro Prieto Geothermal Field, B.C., México

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Abstract. Gas equlibria methods involving Fischer-Tropsch-Pyrite-Magnetite; and Fischer-Tropsch-Pyrite-Hematite-Pyrite-Magnetite reactions were used to evaluate reservoir temperature and a mass steam fraction in Cerro Prieto geothermal field. These approaches have been applied in some selected producing wells from four areas under exploitation. The results show good correlation for both equilibria methods; however Fischer-Tropsch; Pyrite-Magnetite reactions provide the best estimation of the physical reservoir parameters. The main processes found for Cerro Prieto IV area are lateral vapor contribution and the inflow of hotter and deeper fluid with high liquid saturation.

Key words. Cerro Prieto, gas geochemistry, geothermal field

1 Introduction

Non-condensable gases composition is mainly used to identify reservoir processes in vapor-dominated reservoirs; however, it has been also effective in those reservoirs that become vapor dominated after large-scale exploitation or in those reached by injected fluids. The method developed by D'Amore and Truesdell (1985) has been applied by several authors (D'Amore and Truesdell, 1995; Siega et al., 1999; Barragán et al., 2000) in vapor dominated reservoirs. The theory has been thoroughly described in D'Amore (1992), Siega et al. (1999), Barragán et al. (2000). Using gas chemical reactions, which are assumed to be in equilibrium at reservoir conditions, and the chemical composition measured at the discharge of producing wells was found good correlation with temperature (t) and excess vapor (y) in the reservoir. Two correlations were applied in Cerro Prieto: the Fischer-Tropsch (breakdown of methane)-Pyrite-Magnetite and Fischer-Tropsch-Pyrite-Hematite, to define if these reactions can determine the equilibrium between these gaseous species.

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2 The Cerro Prieto Geothermal Field

The Cerro Prieto Geothermal Field (CPGF) in Baja California is located in the southern part of the Salton Trough about 20 miles south of the United States-Mexico border. It is contained mostly in sandstones and shales of the Colorado River delta. Figure 1 shows the location of the CPGF, drilled wells marked by crossed circles wells selected for this work. At present, for administrative purposes four areas have been recognized and the total installed capacity is 720 MW (Gutiérrez and Rodriguez, 2000). There are three reservoirs developed in sandstone and sandy shale units that are fed by fluids rising from fractures, (Lippmann et al., 1991). The alpha reservoir in the west part of the field is the shallowest and was the first to be exploited. It is found at depths between 1000 and 1500 m. The deeper Beta reservoir extends underneath the entire area of the Cerro Prieto (about 15 km^2) at depths between 1500 and 2700 m with temperatures higher than those found in Alfa reservoir. The deep Gamma reservoir is not yet exploited.

2.1 Geologic setting

Tectonically, the Salton Trough-Gulf of California area is a zone of transition between the divergent boundary of the East Pacific Rise and the transform boundary of the San Andreas Fault system.

The sediments at Cerro Prieto were deposited mainly in alluvial, deltaic, estuarine and shallow-marine environments during Pliocene to middle Pleistocene times (Halfman et al., 1984). The sediments are classified in two units A and B, both overlying a granodioritic basement. Unit A consists of clay, silt, sands and gravel; considered as unaltered unconsolidated sediments. Unit B, below unit A, consists of shale, siltstone and sandstone. Sediments of unit B are considered to have become indurated by compaction, cementation and metamorphic reactions. The contact between the A and B units approximately corresponds to the first occurrence of hydrothermal minerals.

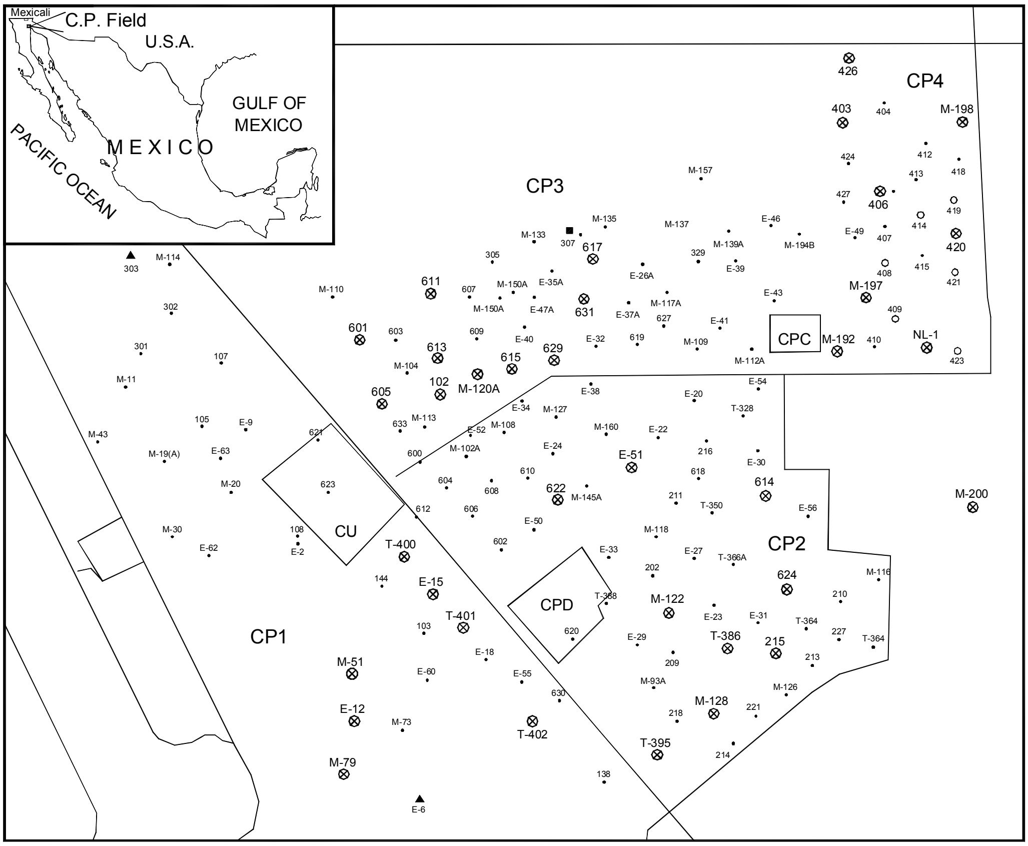

Fig. 1. Location of the Cerro Prieto geothermal field and the producing wells.

2.2 Hydrothermal mineralogy

According to the mineralogical study from Izquierdo et. al. (2001) rock alteration in the area of Cerro Prieto IV (CP-IV) is close to 40% with respect to primary minerals, therefore hydrothermal alteration was defined as high rank and moderate intensity. The rocks are terrigineous being shales more abundant than sandstone and the mineralogy quite similar to all over the field. Minerals identified in the clay fraction are: Na-smectite, Ca-smectite, illite, chlorite and scarce interstratified minerals. Minerals like quartz, plagioclase and amphibole were also identified. Optically calcite, quartz, epidote, illite, chlorite, smectites, wairakite, pyrite, amphiboles, ion oxides (hematite and magnetite) and scarce biotite were recognized. So, the main mineral associations observed in altered rock are: Calcite-illite-epidote-chlorite; -quartz-chlorite; -epidote-wairakite; -epidote-amphibole and wairakite-epidote-pyrite. These mineral assemblages show that the temperature in the zone was between 250°C and 300°C.

2.3 Fluids geochemistry

Being a dominated liquid reservoir, the CP-IV wells produce a mixture of fluids at the surface conditions. The liquid fraction from studied wells has a chemical composition characteristic of a geothermal brine. According to the Piper classification the CP-IV brine can be defined as the sodium-chloride type. Apart of these major elements, content of potassium and calcium are high, while lithium, boron and sulfate content is very low. Stable isotopic composition ($\delta^{18}O$ and δD) for the same fluids at the discharge are in the range of −89.8‰ to −96.7‰ for deuterium and −7.3‰ to −9.4‰ for oxygen-18. The stable isotopes indicate that the natural recharge to the reservoir consists of groundwater from the alluvial aquifer located in the west part of CP-IV area. The main gases for CP-IV are CO_2 (91 w%), H_2S (4 wt. %) and CH_4 (3 wt. %) and together represent over 98 wt. % in dry basis.

3 Results and discussion

Gas equilibria for this study deals with the use of the following gas equilibrium reactions namely Fischer-Tropsch (FT)-Pyrite-Magnetite (HSH) and Fischer-Tropsch (FT)- Pyrite-Hematite- Pyrite-Magnetite (HSH2).

$$\mathbf{FT}: CH_4 + 2H_2O = CO_2 + 4H_2$$

$$\mathbf{HSH}: H_2 + 2H_2O + 3/2FeS_2 = 3H_2S + 1/2Fe_3O_4$$

$$\mathbf{HSH2}: 5/4H_2 + 3/2FeS_2 + \frac{3}{4}Fe_2O_3 + 7/4H_2O = 3H_2S + Fe_3O_4$$

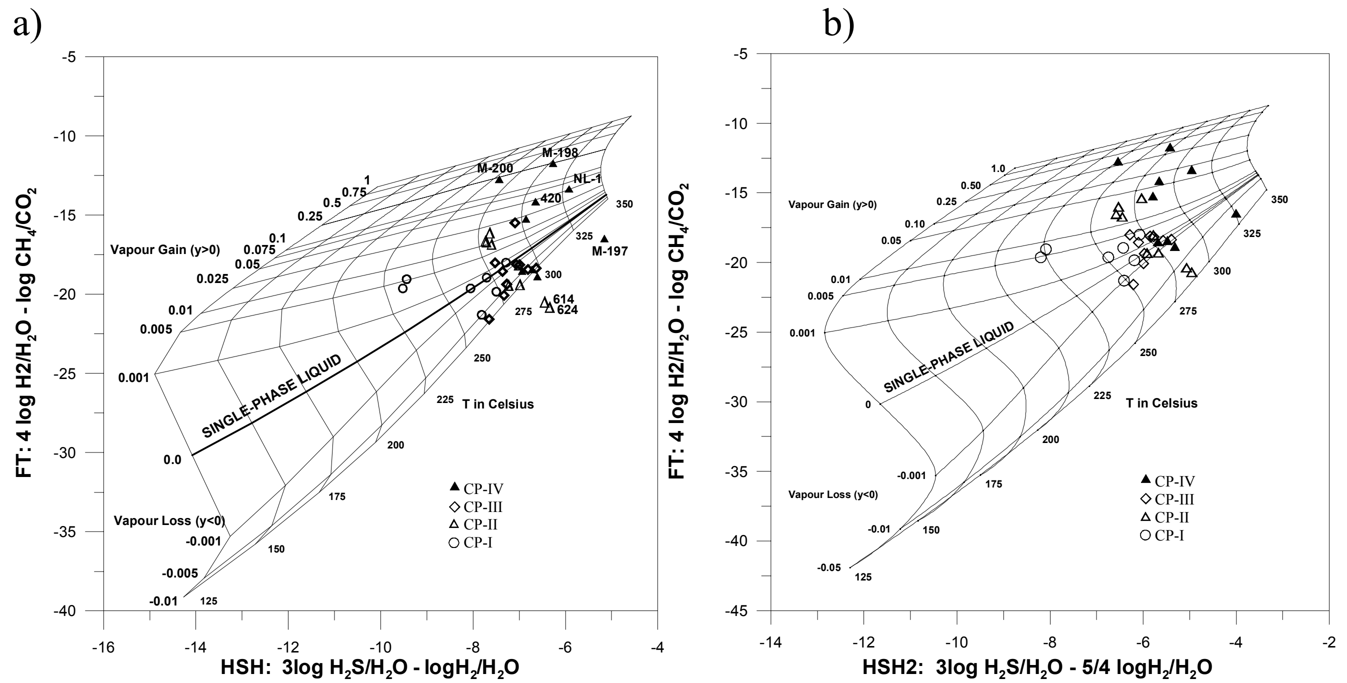

Fig. 2. (a) FT-HSH grid diagram; **(b)** FT-HSH2 grid diagram.

Figure 2 shows the FT-HSH and FT-HSH2 grids diagrams for CP-IV wells and some selected wells from the other areas of Cerro Prieto. In Fig. 2a, excess and deficit of vapor events are shown. Data points of the wells plot on and close to the single-phase liquid line and most of them with negative y values (-0.1% up to -1%). 614 and 624 wells (Cerro Prieto II) plot outside the grid. Furthermore, M-192 and M-197 wells (CP-IV) that plot outside the diagram yield inconsistent y values. The values of temperature and excess steam for most of the wells are in the range from 230°C to 330°C and between 0.1% and 25% are estimated by this gas equilibria method. Higher values for both (y and T) reservoir parameters were found for 403, 420, NL-1 M-198 and M-200 CP-IV wells; which may indicate lateral contribution of steam with strong local accumulation of gas. The CP-IV values of these parameters are in agreement with those calculated by cationic geothermometers (t_{nkc} and t_{ccg}) and by FT equilibrium (Barragán and Nieva, 1989) respectively.

Figure 2b shows data on the HSH2 diagram. As is seen, all of them plot inside the grid, nevertheless both cases of excess and deficit of vapor prevails. The distribution of the data points in FT-HSH2 grid is very similar than FT-HSH; however, slightly low reservoir temperature and also slightly high y values were estimated. Therefore, FT-HSH2 gas equilibria reactions seem to give good characterization for the data used in this study. The temperature estimations are in the range of 230°C to 315°C, in agreement with those given by mineral assemblages.

4 Conclusion

In Cerro Prieto, both gas equilibria methods can be applied to characterize the fluids from producing wells. FT-HSH2 gas equilibria give consistent $\boldsymbol{t}$ values with respect to the mineral assemblage temperature reported previously and all data points plot inside the grid. While both physical reservoir parameters ($\boldsymbol{t}$ and y) estimated by FT-HSH are in good agreement with those estimated by cationic geothermometers (t_{nkc} and t_{ccg}) and FT equilibrium, compared to the values estimated by FT-HSH2 method.

The high excess vapor estimated for 403, 420, M-200, NL-1 and M-198 in Cerro Prieto IV may be due to the inflow of the lateral vapor contribution. In contrast, negative y values and high reservoir temperature estimation for M-197 fluid seem to be result of the inflow of hotter and deeper fluid with high liquid saturation.

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