The Los Humeros Geothermal Reservoir, Puebla, Mexico

Georgina Izquierdo, Víctor M. Arellano, and Alfonso Aragón

Instituto de Investigaciones Eléctricas, Morelos México
gim@iie.org.mx.

Keywords
Los Humeros geothermal reservoir, hydrothermal mineralogy

ABSTRACT

The Los Humeros Geothermal Field has been subject of numerous geochemical and mineralogical studies apart from other disciplines. Based on initial conditions such as geological, geochemical, geophysical, production data and reservoir engineering a basic model of the Los Humeros geothermal reservoir was proposed (Arellano et al., 1998). From this work it was concluded that in LHGF there exist at least two reservoirs.Fluid geochemistry has shown the occurrence of a mixture of fluids; which have been classified as of the bicarbonate type for the shallow reservoir and of the sodium chloride type for the deep reservoir. Mineralogy in the rocks of the two zones is related to the type of rock, temperature and the amount of water in the geothermal system. From the evaluation of hydrothermal mineralogy, lithology and fluid inclusion, cooling of the reservoir is discarded. No conclusive evidences of deep fluid recharge exist; instead migration of deep fluids is evident in chemical and physical fluid parameters.

Introduction

The Los Humeros geothermal field (LHGF) is administrated by the Comisión Federal de Electricidad (CFE, Federal Electricity Commission) as the third geothermal resource in Mexico. 40 geothermal wells have been drilled, 20 of them are producers feeding seven 5 eMW power plants (Quijano and Torres, 1995).

As a promising area, LHGF has been subject of study in many disciplines. Since the beginning of the exploitation the idea of at least two reservoirs was mentioned by several authors. Later, based on initial conditions such as geological, geochemical, geophysical, production data and reservoir engineering a basic model of the Los Humeros geothermal reservoir was proposed (Arellano et al., 1998). From this work it was concluded that in LHGF there exist at least two reservoirs. The shallower one, contained in the augite andesite unit, seems to be located between 1025 and 1600 m.a.s.l. and is defined as liquid dominant; giving excellent agreement with the boiling point pressure for depth curve, with a pressure profile corresponding to hydrostatic gradient at a temperature of 300-330°C.

The deeper reservoir is located in the hornblende andesite unit between 850 and 100 m.a.s.l. and is considered as a low liquid saturation reservoir. The change of the pressure distribution slope at about 900 m.a.s.l. was interpreted as the occur-

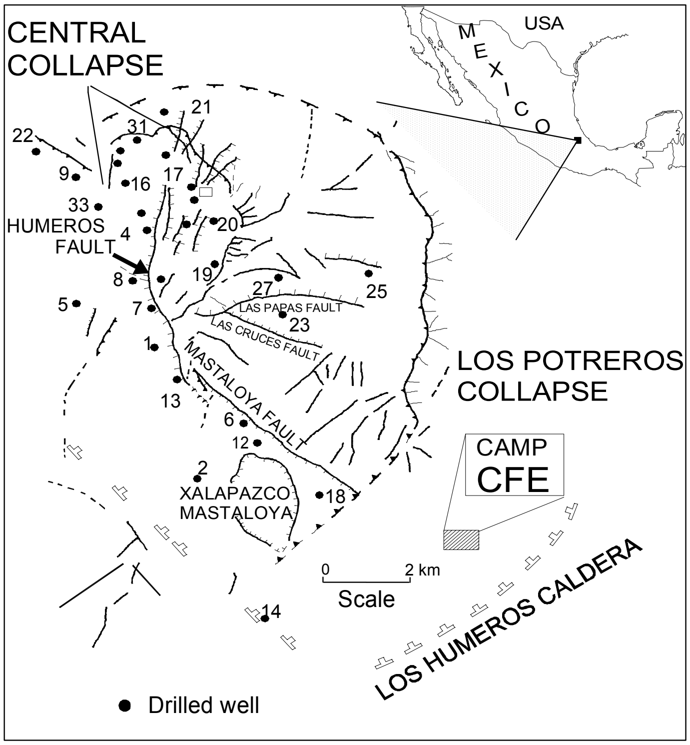

Figure 1. LHGF location of wells and main geological structures.

rence of an impermeable barrier separating the two reservoirs. This barrier could be the low permeability vitreous tuff; which in some wells it is absent, in other is a narrow layer of less than 100m and in other wells is less than 170 m thick.

Because of the accelerated corrosion observed in some wells mainly located in the Colapso Central, it was though on the occurrence of an acid reservoir hosted in the hornblende andesite. The occurrence of such reservoir has been discarded (Arellano et al., 1998; Izquierdo et al., 2000).

In order to avoid "acidic" fluids production, the CFE decided to plug with cement some of the wells drilled in the Central Collapse area. After some years deep volatiles components have modified the fluid chemistry.

Inconsistencies in fluid geochemistry, mineralogical and fluid inclusions data have given rise to what could be misinterpretation of interpretation; that have been translated from one paper to other. Based mostly in information already published on LHGF a brief discussion on the reservoir of LHGF is presented.

Geological Setting

The Los Humeros geothermal field (LHGF) is located in the eastern part of the Mexican Volcanic Belt (Figure 1). The volcanic system has several geological structures, where the main feature is the Los Humeros Caldera. This structure has a diameter of 16 km and contains the Los Potreros collapse. Small structures have been recognized such as the Central and Xalapazco collapses and Mastaloya and Los Humeros fault system. Wells drilled in the Central Collapse have shown the highest temperatures of the area.

The subsurface geology (taken from Cedillo, 1997), is the result of the interpretation of petrological and geophysical logs that have contributed to identify hidden faults and to subdivide the four lithological units previously recognized (Viggiano and Robles, 1988 a) into nine lithological units. From the basement to the surface 1.- limestone, metamorphic limestone and intrusives, 2.- basalts, 3.- hornblende andesite (HA), 4.- vitreous tuff, 5.- augite andesite (AA), 6.- intercalation of andesites and ignimbrites, 7.- ignimbrites, 8.- lithic tuffs and ignimbrites and 9.- pumice, basalts and andesites.

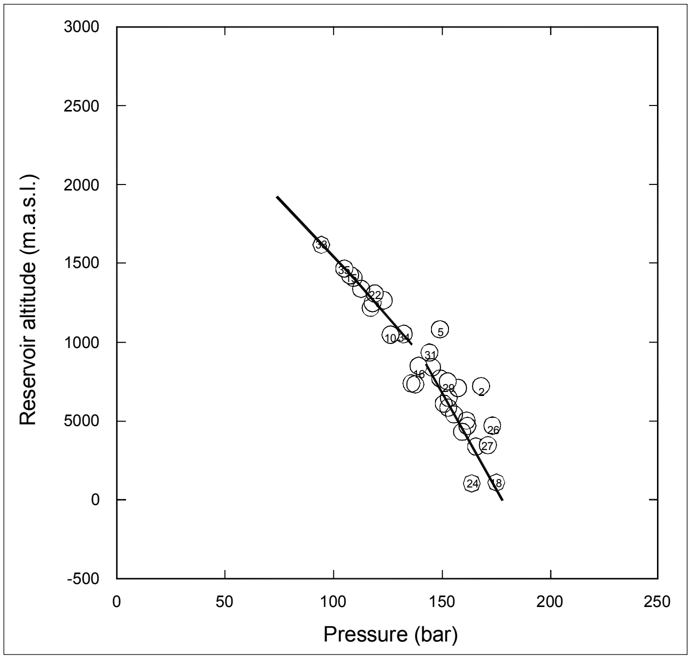

Figure 2. Unperturbed pressure-altitude profile. For simplicity not all the well numbers are shown. (from Arellano et al., 2003).

Units 9 is of high permeability while units 2, 3, 5 and 8 are considered to have medium permeability. Units 3 and 5 host the geothermal reservoir.

The distribution of limestone in the area of Los Humeros acts as a fence surrounding the field. At present rainfall is considered as the main recharge source flowing down through faults and fractures.

Discussion

As it was pointed out from initial production data and reservoir engineering the occurrence of at least two reservoirs in LHGF has been evident; separated maybe by an impermeable layer (Figure 2). Most of the wells produce a mixture of fluids; it has been considered that the AA produces liquid, vapour and possibly a condensed fluid and the HA produces a low liquid saturation fluid. Fluids from the shallow reservoir have been classified of the bicarbonate type and fluids from the deep reservoir of the sodium chloride type (Barragán et al., 1991; Arellano et al., 2003).

In the area of the Central Collapse (CC) wells behave in a different way than wells outside this area. Wells in CC produce high enthalpy fluids and corrosion of pipes has been a problem; while wells outside the CC produce a mixture of fluids without corrosion of pipes.

Wells in the CC have gone through AA and just 100 to 170 m of HA and through a relative narrow vitreous tuff unit. Producer wells outside the CC have gone trough AA, vitreous tuff and a thick HA strata.

We believe that what makes the difference is the location of the wells does not matter if they were through AA and HA or where plugged avoiding fluids from the HA. So, wells in the CC may indicate that the heat source should be close transferring heat and volatiles; ascending through the HA and mixing with fluids from the AA.

Mineralogical Differences Between the Two Andesitic Units

In wells located in the Central Collapse at depth the low intensity of alteration caused by the hydrothermalism in cores and cuttings is an indication of the low water : rock ratio. The relative highest alteration percentages are found in the AA unit which is considered to be the two phase reservoir. In deep strata rock alteration is low, and sometimes it is common to find almost unaltered rocks.

Some authors have referred to the HA as the acidic reservoir because some wells presented accelerated corrosion. No evidence of minerals formed by the interaction of acid fluids with the rocks were found.

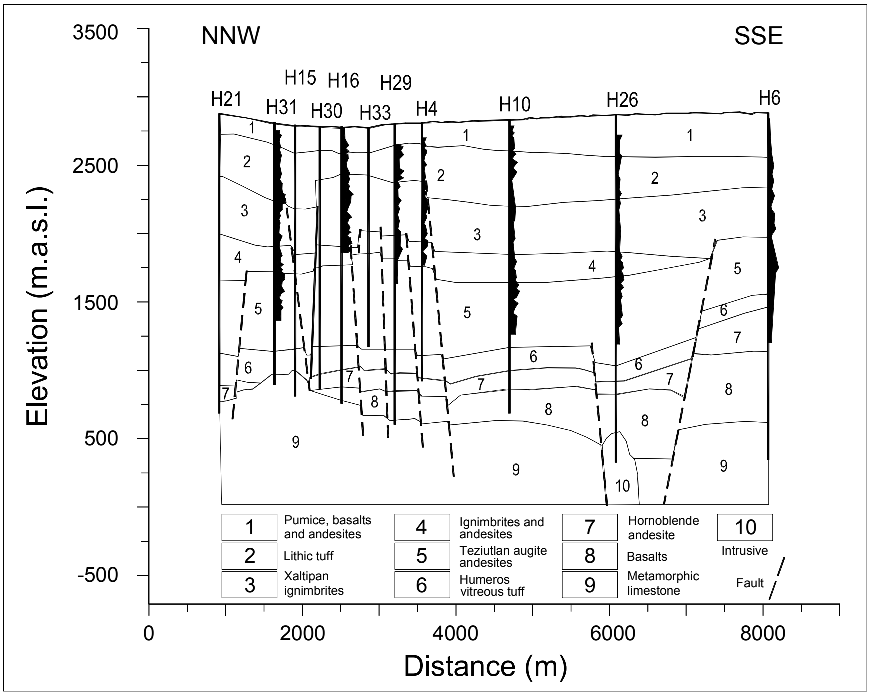

Figure 3. Geological cross section indicating the occurrence of calcite.

The "acid" wells are located in the area of the Central Collapse such as H-4, H-11, H-16 and H29 and others. The main hydrothermal minerals found are: chlorite, epidote, quartz, calcite, low proportion of leucoxene and pyrite. Apart from these minerals: clays, biotite and in low amount zeolites, anhydrite, amphibole, garnet, diopside and wollastonite have been recognized. In agreement with Reyes (1990), the pH conditions in which these minerals are formed are considered as for neutral to alkaline environments. Garnet, diopside and wollastonite are related to the granitic-granodioritic basement or to the metamorphosed limestone which are found only in wells H-7, H-9, H-17, H-28 y H-29.

From the petrographic file, provided by the Comisión Federal de Electricidad, the percentage of some of the alteration minerals was taken; calcite and epidote being the most indicative. Its distribution was represented in several geological sections (taken from Cedillo, 1997). Figures 3 and 4 show the distribution of calcite and epidote in wells located in the geological section which includes wells H-21, H-31, H-15, H-30, H-16, H-33, H-29, H-4, H-10, H-26 and H-6. Wells H-31, H-15, H-30, H-16, H-33, H-29, H-4 and H-10 are located within the Central Collapse. In Figure 3 it is observed that calcite is distributed from shallow depths to the AA. At greater depth, calcite is scarce in wells that produce mixture of fluids and is absent in wells producing low liquid fraction. The absence of calcite at depth is the result of the low water : rock ratio that exists in the vapor zone and not because of the presence low pH fluids as it once was mentioned. This same behavior is observed in Figure 4 where epidote distribution is presented. In wells from the CC the biggest proportion of epidote is located in the upper andesite and extends in minor proportion to the lower andesite. In other wells epidote occurs as expected as function of depth and temperature.

Features like water:rock ratio, temperature and hydrothermal mineralogy make the difference between the upper and the lower andesite. Wells like H-12 and H-6 drilled at the south of the field close to the Xalapazco structure are the deepest in the field. Well H-6 was through AA from 910 to 1570 m, to the vitreous tuff from 1570 to 1670 m, to the HA from 1670 to 2470 m and finally to the metamorphosed limestone from 2470 to 2541 m. Well H-12 was through AA from 920 to 1630m, to the vitreous tuff from 1630 to 1760 m, to HA from 1760 to 2490 m, to rhyodacite from 2490 to 2680 m, to basalts from 2680 to 2730 m and to the granite from 2730 to 3104 m. At present H-6 is the third producer of liquid phase and H-12 the eight producer of liquid phase. Both are producing from the two andesitic units without damage to the pipes. In contrast well H-4 drilled at a maximum depth of 1880 m, was through AA from 1060 to 1860 m and to the vitreous tuff from 1860 to 1880 m. This well was shut down before production started because of the accelerated corrosion and emission of large amount of H_2S.

Other example are well H-16 and H-29 both with a well documented history due to the effects of corrosive fluids. Both are located in the Central Collapse. H-29 now is an injection well and well H-16 is a producer well.

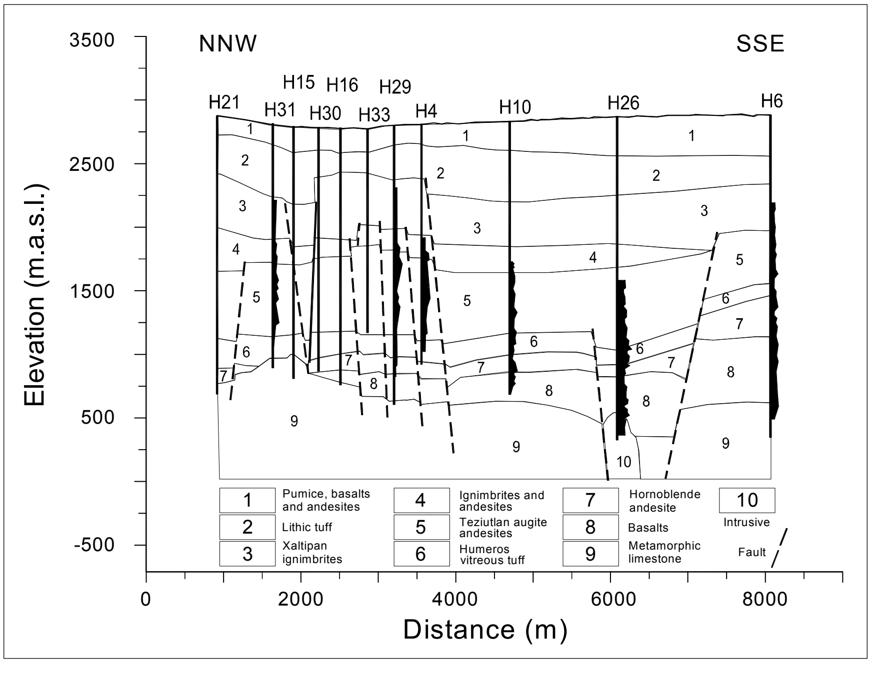

Figure 4. Geological cross section indicating the occurrence of epidote.

Well H-29 was drilled at a maximum depth of 2200 m afterwards it was repaired. Was through AA from 1020 to 1750 m, vitreous tuff from 1750 to 1890 m, HA from 1890 to 1960 m and basalt from 1960 to 2022 m.

Well H-16 was through AA from 910 to 1670 m, to the vitreous tuff from 1670 to 1800 m, to HA from 1800 to 1950 m, to basalt from 1950 to 2014 m and to metamorphosed limestone from 2014 to 2048 m. As this well showed accelerated corrosion it was plugged at the level of AA. Production data showed increase of pH for sometime; now data indicate that pH started to decrease even the plug is there (V. M. Arellano, personal communication). This fact may indicate that deep magmatic fluids continue in activity moving upwards.

Wells H-4, H-16 and H-29 were not through HA; however aggressive fluids were produced not for the lower andesite but the nearness to the magmatic source.

The difference between these wells and H-6 and H-12 is that wells H-4, H-16 and H-29r are drilled in the Central Collapse. In this area some remarks can be made such as the hottest registered temperatures, very low amount of water, no recharge at all or evaporation of any water, intense fracturing; as well as presence of magmatic volatiles that have transformed the chemistry of fluids. While wells H-6 and H-12 located outside the Central Collapse, close to the Mastaloya fault are receiving some recharge as well as wells drilled along the Mastaloya fault. So production of steam is not related to the HA reservoir; it is related to the amount of recharge and recharge is related to the location of wells in the field.

Fluid inclusion studies in samples from wells of LHGF has been a difficult task; since cuttings for most of the wells are of very small size and the amount of transparent secondary minerals, such as quartz and calcite, is reduced and the majority of fluid inclusions are tiny. However samples from different wells have been studied by researchers from the Instituto de Investigaciones Eléctricas.

Most fluid inclusions are of the water-vapor type with varying proportions of each one of the phases; at depth single vapor phase inclusions were observed. All samples show the presence of a low salinity fluid.

Deep small calcite fragments showed the presence of non aqueous fluid inclusions. From their behavior on heating, after cooling at –150°C, it is assumed the presence of CO_2, methane and hydrocarbons.

No high salinity fluid inclusions were observed; instead the occurrence of gas inclusions is an indication of mobility of deep fluids favored by the permeability of the basement.

Homogenization temperature increases progressively from the shallow levels to deepest studied samples. In most of the wells samples close to the vitreous tuff or in the hornblende andesite show a decrease in homogenization temperature; this fact has been considered for other authors as an inversion of temperature and together with the occurrence, at depth, of Ca-smectite it was interpreted as cooling of the system. At present it is well known that Ca-smectite may be stabilized and resist temperatures as high as 300 °C. We assume that the drop in Th may be related to the boiling process when the system was not exploited.

Direct methods of temperature measurements (temperature logs from CFE) as well as calculated temperatures (Arellano et al., 2003) have indicated that the hottest area is within the Central Collapse. For example isotherms close to well H-29 show 300 ºC at a depth of 1300 m. Homogenization temperature at 1500 m for the same well is 342 ºC.

Conclusions

Based on the presence of Ca- montmorillonite at depth and drop of Th at depth, cooling of the system is discarded.

The slight decrease of Th in the deepest samples maybe explained by the boiling process in the low liquid saturation strata. Boiling may be considered although there are not reported sets of microthermometric data showing boiling. Detailed studies on this subject are highly recommended in order to confirm this conclusion.

There are two different zones considered as two reservoirs, one of a mixture of fluids and the deep one with low liquid saturation. The mineralogy in each zone depends mostly on the amount of water interacting with the rock.

The vitreous tuff should not be considered as an impermeable layer or as a seal. The tuff had hydrothermal alteration and with it movement of fluids through it.

At present no evidence of fluid recharge of the reservoir are conclusive; instead migration of deep magmatic fluids are evident.

An acidic reservoir is discarded, since the acidy is not formed in the hornblende andesite as once was thought. The acid species from a deep magmatic source are moving upwards in the vapour phase when they reach the two phase zone they mix with water becoming reactive. This process only occurs in wells drilled in the Collapso Central.

At present no conclusive evidences of a important recharge of the shallow production strata exist; but the main steam producer wells are in the Central Collapse where no recharge evidence in this area is recorded.

At depth in HA in wells outside the Central Collapse there is little fluid recharge; instead in wells in the Central Collapse migration of deep fluids is evident from the changes in pH observed in wells that once were plugged.

Large amounts of B detected at the discharge of wells located not only in the Central Collapse confirm migration of deep magmatic fluids.

References

Arellano V. M., A. García, R. M. Barragán, G. Izquierdo, A. Aragón, D. Nieva, E. Portugal and I. Torres. 1998. desarrollo de un modelo básico actualizado del yacimiento geotérmico de Los Humeros, Puebla. Internal Report Instituto de Investigaciones Eléctricas, Cuernavaca, México. Informe IIE/11/11459/01/F.

Arellano V.M., G. Izquierdo, A. Aragón., R.M. Barragán and A. García. 2001. Distribución de presión inicial en el campo geotérmico de Los Humeros, Puebla, México. Ingeniería Hidráulica en México. V. XVI, No 3, pp. 75-84 julio-septiembre.

Arellano V. M., A. García, R. M. Barragán, G. Izquierdo, A. Aragón and D. Nieva. 2003. An updated conceptual model of The Los Humeros

(México) geothermal reservoir. Journal of Volc. and Geoth. Res. 124, 67-88.

Barragán R., Nieva D., Santoyo E., Verma M. and López M. 1991. Geoquímica de fluidos del campo geotérmico de Los Humeros, (México). Geotermia, Rev. Mex. Geoenergía. 7, 1, 23-47.

Cedillo R. F., 1997. Geología del subsuelo del campo geotérmico de Los Humeros, Pue. Informe HU/RE/03/97, Comisión Federal de Electricidad. Gerencia de Proyectos Geotermoéléctricos. Residencia de Los Humeros, Puebla, p. 30.

Cedillo R., F. 2000. Hydrogeologic model of the geothermal reservoirs from Los Humeros, Puebla, México. Proc. World Geothermal Congress 2000, Kyushu-Tohoku Japan, May-June 2000, pp. 1639-1644.

Georgina Izquierdo, Victor Manuel Arellano, Alfonso Aragón, Enrique Portugal and Ignacio Torres, Fluid acidity and hydrotermal alteration at the Los Humeros geothermal reservoir, Puebla, México. Proc. World Geothermal Congress 2000, Kyushu-Tohoku Japan, May-June 2000, pp. 1301-1306

Martínez-Serrano R. G. 2002. Chemical variations in hydrothermal minerals of the Los Humeros geothermal system, Mexico. Geothermics 31, 579 – 612.

Quijano J. L. and Torres M. 1995. The Los Humeros geothermal reservoir, a case of very high temperature system. Proc. World Geothermal Congress, 3, p. 1569-1573.

Reyes A., 1990. Petrology of Philippine geothermal systems and the application of alteration mineralogy to their assessment. J. of Volc. and Geoth. Res. 43, pp. 279-309.

Viggiano J.C. and Robles J. 1988. Mineralogía hidrotermal en el campo geotérmico de Los Humeros, Pue. I: Sus usos como indicadora de temperatura y del régimen hidrológico. Geotermia. Rev. Mex. de Geoenergía, 4, 1, 15- 28.