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Considerations on the Origin of Acid Fluids in Los Humeros Geothermal Field, Pue., Mexico

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ABSTRACT

The Los Humeros geothermal field is one of the four geothermal fields currently operating in Mexico. It has an installed capacity of 40 MW with eight back pressure units of 5 MW each. The Los Humeros system has been the subject of a great number of studies on different subjects. From the geochemical and geological points of view some inconsistencies have been reported. The occurrence of low pH fluids in wells of one of the most profitable area of the field has been related to a deep acid reservoir. Additionally it has been suggested the existence of at least two reservoirs. At present, it is considered that there is a single reservoir hosted in Tertiary andesites, 1200 m thick in average, with several feeding zones. Fluids at the discharge are a mixture of steam and a low liquid fraction. No evidence of an acid reservoir has been found. In this work conclusions of the occurrence of acid fluid in the Los Humeros reservoir are presented.

Introduction

The Los Humeros geothermal field (LHGF) is located in borders between the state of Puebla and the state of Veracruz, at central-eastern Mexico (FIgure 1). The field is inside the Los Humeros volcanic caldera, which lies at the eastern end of the Mexican Volcanic Belt near the limit of this province with the Sierra Madre Oriental province.

Los Humeros is one of the four geothermal fields currently operating in Mexico. It has an installed capacity of 40 MW with eight back-pressure units of 5 MW each, which are fed by an average of 20 production wells that produce around 500 tons of steam per hour. There are also three injection wells in operation. The geothermal field is administrated by the Comisión Federal de Electricidad (CFE) of Mexico.

CFE has planned to increase the installed capacity by 46 MW with the project Los Humeros II in two phases. Phase A consists of

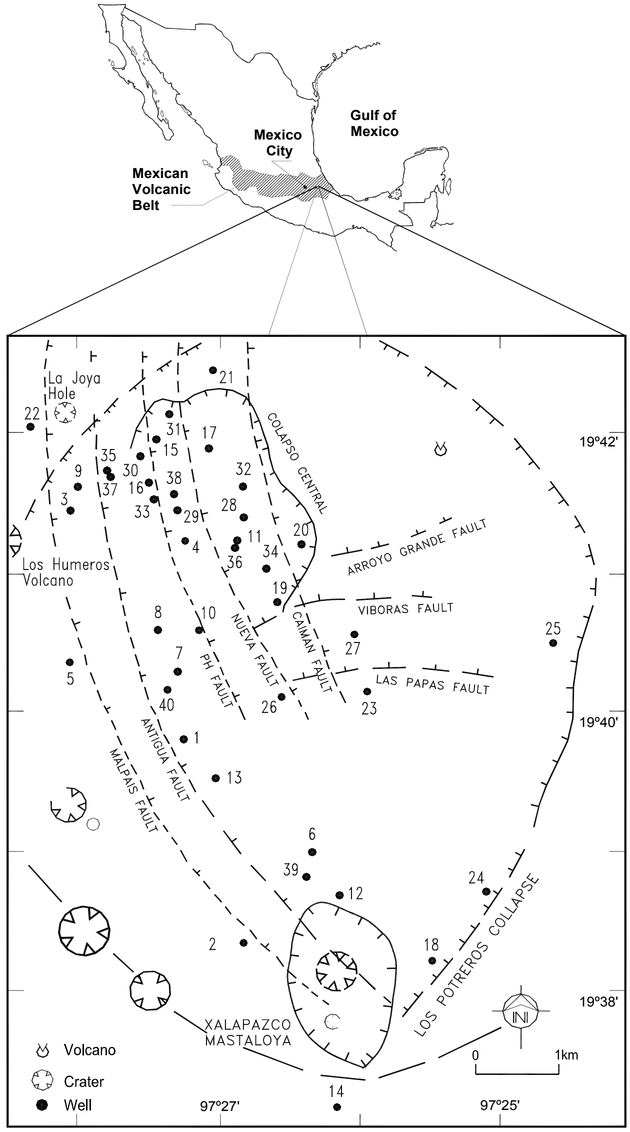

Figure 1.

one condensing unit of 25 MW and phase B consists of seven binary units of 3 MW each, to be installed in seven of the 5-MW back-pressure units in operation that will use the exhausted steam from the binary plants.

One special feature in the Los Humeros is the occurrence of fluids of low pH in wells drilled in the area of the Colapso Central, particularly at more than 1800 m depth. It was proposed that acid fluids came from a deep acid geothermal reservoir, probably located in the hornblende andesites, but this has been discarded (Izquierdo et al., 2000). Instead, the formation of low pH fluids is explained as a post-exploitation process related to the migration of deep magmatic volatile species, induced by the extraction of fluids from the reservoir. The volatiles such as CO_2, H_2S, Cl, F, etc., react in their way to the surface with aqueous fluids, producing aqueous corrosive species

In this paper we assume the occurrence of a single reservoir in LHGF (Izquierdo et al., 2008; Gutierrez-Negrin and Izquierdo-Montalvo, 2009) constrained by geologic structures that favored the formation of acid fluids in wells drilled in the area of the Colapso Central. As there is no evidence of a deep acid reservoir, no mineral indicators of an acid environment may used to explain the acidity in LHGF wells.

Geologic Features

Volcanic activity in the Los Humeros area started in the Miocene, around 10 Ma ago. It was essentially of fissure type and produced the Alseseca Andesites that outcrop at the northeastern part of the Los Humeros caldera and cover the calcareous rocks (Yáñez-García and Casique-Vazquez, 1980). Volcanic activity stopped until the Pliocene, when began the volcanism associated to the Mexican Volcanic Belt and the Teziutlán Andesites were formed between 3.5 and 1.9 Ma.

The caldera process began 0.51 Ma ago when a highly differentiated magmatic chamber was emplaced into the Mesozoic calcareous package. The magmatic chamber produced a flexure on the overlaying volcanic rocks and left a circular weakness zone through which were erupted a series of rhyolitic domes. After these peripheral domes were emplaced, (around 0.46 Ma) some gasification occurred at the upper zone of the magma chamber. The excess of pressure was released as a series of explosive eruptions through a central vent; the eruptive columns collapsed at their lower parts and produced pyroclastic flows. Cooling and consolidation of these flows formed the Rhyolitic Xaltipan Ignimbrite. The sudden release of a large amount of magma triggered the gravitational collapse of the overlaying rocks, giving place to the Los Humeros caldera with a major diameter of 21 km and a minor diameter of 15 km (Yáñez-Garcia and Casique-Vázquez, 1980; Ferriz and Mahood, 1984).

One hundred-thousand years ago explosive eruptions provoked a new collapse known as the Los Potreros caldera (FIgure 1). This caldera is nested inside the southern portion of the Los Humeros caldera, and presents a diameter between 7 and 10 kilometers (Yáñez-Garcia and Casique-Vazquez, 1980; Ferriz and Mahood, 1984).

Between 40,000-60,000 years after the Los Potreros collapse, other volcanic eruptions produced several volcanic products including the Arenas and Maztaloya volcanoes, the latter with an explosion crater of 1.7 km in diameter (the Maztaloya Xalapazco, Figure 1). The local volcanism seems to have finished around 20,000 years ago. Since then a geothermal system has been forming at the subsurface, whose heat source is the magmatic chamber that is in its last hydrothermal stage.

It has been proposed a third collapse-caldera named the Colapso Central, located inside the Los Potreros caldera (De la Cruz-Martinez, 1983). It has been suggested that the Colapso Central shows a morphologic feature produced by the arrangement of superficial lava flows (Garduño-Monroy et al., 1985). The location of the Colapso Central coincides with the upflow zone of the geothermal system and probably with the magma chamber at depth.

From a detailed study of drill cuttings from 42 wells and making a synthesis of the previously proposed geologic units (Gutiérrez-Negrín, 1982; Viggiano and Robles, 1988) the subsurface lithology can be grouped into four units that are from the top to bottom (Table 1):

Unit 1. Post-caldera volcanism. Quaternary (<100,000 years). It includes all the volcanic rocks and products formed after the second caldera collapse and are composed of andesites, basalts, dacites, rhyolites, flow and ash tuffs, pumices, ashes and materials from phreatic eruptions. The unit contains shallow aquifers, some of them locally thermal.

Unit 2. Caldera volcanism. Quaternary (510,000-100,000 years). This unit is mainly composed of lithic and vitreous ignimbrites from the two collapses (Los Humeros and Los Potreros) which form the Xaltipan and the Zaragoza ignimbrites, respectively. It also includes products of the volcanic events that occurred between both collapses, as rhyolites, pumices, tuffs and some andesitic lava flows, as well as the peripheral rhyolitic domes emplaced before the first collapse. This unit acts as an aquitard (Cedillo, 2000).

Table 1. Main lithologic units and characteristics of the subsurface at Los Humeros.

Unit	Description	Age	Thickness	Characteristics
1	Post-caldera volcanism. Andesites, basalts, rhyolites, dacites, tuffs, ashes, pumices.	Quaternary (<100,000 years)	Minimum: 90 m Maximum: 1010 m Average: 340 m	It forms shallow hot and cold aquifers. High-medium permeability.
2	Caldera volcanism. Ignimbrites Xaltipan and Zaragoza, with andesites, pumices, rhyolites, tuffs.	Quaternary (510,000-100,000 years)	Minimum: 185 m Maximum: 880 m Average: 600 m	It forms aquitard and acts as a cap rock. Low permeability.
3	Pre-caldera volcanism. Hornblend andesites (Alseseca?) and augite andesites (Teziutlán), with tuffs, basalts, dacites, rhyolites.	Tertiary (Miocene-Pliocene) (10-1.9 Ma)	Minimum: 90 m Maximum: 2600 m Average: 1200 m	It contains the geothermal fluids. Medium-low permeability.
4	Basement. Limestones and subordinated shales Pimienta and Tamaulipas Superior formations), marble, skarn, hornfels, granitic rocks and minor diabasic and andesitic dikes.	Mesozoic-Tertiary (Jurassic-Oligocene) (140-31 Ma)	Minimum: 13 m Maximum: Unknown Average: 210 m	Low permeability, high temperature. Several wells did penetrate the top.

Unit 3. Pre-caldera volcanism.. Tertiary (Miocene-Pliocene, 10-1.9 Ma). It is composed of thick andesitic lava flows with some Tuff intercala-

tions. The characteristic accessory mineral of the upper andesites is augite, the lower andesites contain mainly hornblende. Both packages include minor and local flows of basalts, dacites and some rhyolites. This unit hosts the geothermal reservoir.

Unit 4. Basement. Mesozoic-Tertiary (Jurassic-Oligocene, 140-31 Ma). This lower unit is composed of limestones and subordinated shales; which were folded and partially and locally metamorphosed by Oligocene intrusions. It also includes intrusives (granite, granodiorite and tonalite) and metamorphics (marble, skarn, hornfels), and eventually some more recent diabasic to andesitic dikes.

Geothermal Fluids and Production

Fluids produced at the wellheads are a mixture of low salinity fluids, most of the wells are fed from different strata. Well H-1 is the only one that has shown the major liquid fraction troughout the years.

Los Humeros wells produce mainly high steam enthalpy (more than 2000 kJ/kg) except well H-1 that produces mainly water with enthalpy of 1100-1300 kJ/kg. Water is chemically homogeneous of type sodium-chloride to bicarbonate-sulfated with high content of boron. Average chloride content in the reservoir is between 25 and 75 ppm, with a maximum of 533 ppm in well H-19 (GENZL-SIHASA, 1993). However, the chemical composition of the liquid phase varies with time and depends on the depth of the well and the diameter of the production orifice.

Acid Fluids in Geothermal Systems, The Los Humeros Case

In most geothermal systems if an aqueous solution of acid nature occurs it tends to be neutralized and becomes alkaline due to its interaction with the reservoir rocks. However, the chemical composition of the fluids collected in the surface may show the presence of components related to the acidity of the geothermal fluid; such is the case of excess of chloride and sulfate and, in consequence they show a chemical unbalance. This is not the case at LHGF, chemical composition of fluids sampled at the wellheads show low salinity and the chemical unbalance is not associated to Cl or SO_4. It rather may be related to the mixture of fluids coming from different strata and to the physical and chemical processes occurring in the reservoir as a consequence of exploitation. At present, fluids sampled at the Wellhead may not be representative of the fluids in the reservoir.

The main acid species commonly found in geothermal environments are HCl and H_2SO_4. Evidence of H_2SO_4 in the LHGF is given by areas of argillic alteration at the surface formed when H_2S rising from the reservoir is oxidized in the vadose zone, and the resulting acid fluids percolate to deeper levels through faults and fissures.

Analysis by X-ray diffraction of superficial samples from distinct zones of the field shows minerals characteristics of the advanced argillic alteration type: alunite, kaolinite, gypsum and small amounts of jarosite, alunogen, and scarcely potash alum. No minerals such as lazulite, topaz ralstonite, danburite, gadolinite and zunyite supported by the presence of SO_2 and excess of Cl in the fluid discharges are found in the LHGF.

To explain the origin of the HCl several approaches are known (Haizlip and Truesdell, 1988; Truesdell et al., 1989; D'Amore et al., 1990; Izquierdo et al., 2000). The transport mechanism of HCl in superheated vapor introduced by Haizlip and coworkers (D'Amore et al., 1990) has been well accepted; we believed is the appropriate the LHGF. On the origin of the HCl, D' Amore et al. (1990) and Truesdell et al. (1989) have suggested that the origin of vapor containing HCl is the product of the high temperature (> 325 °C) reaction between NaCl solid and the rock minerals. The mechanism proposed by these authors considers that in the natural state of a geothermal reservoir, a deep boiling brine should exist that generates ascending vapor required for the transport of heat and gases to the top of the vapor-dominant reservoir. Furthermore, they propose that if this deep liquid exists, it should be concentrated brine due to the accumulation and concentration of solutes. We consider that this is not the case in LHGF; if hot brine would reacts with the basement rocks it would form high salinity brine promoting the formation of Ca minerals. Also intense hydrothermal alteration of deep rocks would be observed in the Colapso Central area.

As it has been pointed out by some authors, the most important species in a geothermal system providing acidity to an hydrothermal fluid are the volatile components that emanate from the magma (H_2O, Cl, SO_2, H_2S, H_2 and $CO_{2)}$. Their interaction with geothermal fluids and the physical-chemical changes that occur in the reservoir generate an acid fluid. In fact, this is what is happening in LHGF, evidence of acid fluids has been observed only in wells close and inside the Colapso Central where evidences of the outflow of the system and the highest temperatures are observed.

At the beginning of exploitation of the reservoir, wells drilled in the Colapso Central produced neutral to basic fluids (except well H-4, which had to be closed due to the production of highly corrosive fluids). After some time wells started to produce fluids of low pH.

An example mentioned in most papers is well H-16 located in the Colapso Central. This well and others had to be repaired in similar conditions by plugging the deep production zones with cement; isolating these zones to prevent the mixing of shallow fluids with deep fluids transporting magmatic volatiles, CFE also decided that wells to be drilled in the area of the Colapso Central should be shallow enough to avoid the deeper production zones. As a result, corrosion and scaling diminishes but also reduces well production rate by more than half. For instance, well H-16 produced initially 48 t/h of steam and 3.6 t/h of water; after repaired it produces 10 t/h of steam and 11 t/h of water approximately.

Recent mineralogical studies (Izquierdo et al., 2008, Gutierrez-Negrin and Izquierdo-Montalvo, 2009) have demonstrated that different water-rock ratios prevailed in the reservoir before the start of commercial exploitation. It was found that the intensity of the hydrothermal alteration varies according to the liquid fraction present in the reservoir, which depends mainly on fluid recharge, temperature and the rock permeability.

The intensity of hydrothermal alteration indicates that in some parts of Los Humeros there is a single geothermal reservoir hosted in andesitic rocks; while in the Colapso Central area the degree of alteration distinguishes two producing zones in the andesites, one with high and the other with low liquid Saturation. The second one is constrained by low or no deep recharge and by the highest temperatures registered associated with the proximity of the heat source. Many papers have been referred to it as the deep reservoir which was believed to be separated from the upper reservoir by a thin vitreous tuff layer. At present it is known that this vitreous tuff does not have an homogeneous distribution all over the field, in consequence it cannot be a caprock as it was originally considered, furthermore zones where the liquid fraction is higher show high degree of hydrothermal alteration.

Conclusions

The produced acid fluids in the LHGF are restricted to wells in the Colapso Central area. As it has been mentioned, the Colapso Central coincides with the up flow zone of the geothermal system and proximity to the magma chamber at depth.

The most probable mechanism of formation of low pH fluids in the Colapso Central is explained as a exploitation-related process due to the migration of deep magmatic volatile species, which are induced by the extraction of The geothermal fluids. The volatiles such as CO_2, H_2S, Cl, F, etc., react in their way to the surface with aqueous fluids, producing aqueous corrosive species.

As no mineral evidence of the interaction of rocks with an acid fluid exist, drilling in the Colapso Central area, should be stopped when the intensity of hydrothermal alteration decreases. Commonly this occurs when the low liquid fraction zone is reached and the accessory mineral augite in andesite changes to hornblende.

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