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Evidence of Deep Acid Fluids in the Los Humeros Geothermal System, Mexico

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ABSTRACT

Los Humeros geothermal field is one of three geothermal fields under exploitation in Mexico. Los Humeros, hosted in a volcanic caldera, is located in the central-eastern portion of the country, within the Mexican Volcanic Belt, near the limit of this province with the Sierra Madre Oriental province.

One special feature in the Los Humeros is the occurrence of fluids of low pH in wells drilled in the area known as the Colapso Central, particularly at more than 1800 m depth. No evidence of a proper of acidic reservoir has been found; instead, the formation of low pH fluids has been explained as a post-exploitation process related to the migration of deep magmatic volatile species. Minerals such as lazulite, tourmaline, pyrophyllite and zunyite have not been found in reservoir rocks; instead, typical mineralogy of neutral to basic environments has been reported.

In a recent ongoing research project, a core from a depth of 2000m was studied. Its physical characteristics show the evidences of its interaction with low pH fluids. Three fragments of the core show a rock of cream color, it is like a porous rock mostly composed by residual quartz. It has been classified as andesite even it does not contain primary or hydrothermal minerals commonly found in this type of rock. By petrography and X-ray diffraction abundant fine crystalline quartz and plagioclases were identified. Traces of chlorite and pyrite were also present. At the time the well was drilled, besides of the circulation lost and high temperature (378 °C), the well was abandoned; so no production data were recorded.

Mineralogical, textural, chemical and petrophysical data supported the evidence of local deep acid fluids in the Los Humeros geothermal reservoir.

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.

One special feature in the LHGF is the occurrence of fluids of low pH in sampled fluids in wells drilled in the area of the Colapso Central; particularly in those drilled at more than 1800 m depth. It has been proposed the occurrence of an acidic deep geothermal reservoir; probably located in the deep andesites (hornblende andesites). As no mineralogical evidence of such fluids affecting deep explored rocks was found, the occurrence of an acidic reservoir has been discarded. (Izquierdo et al., 2000, 2005, 2009). Instead, the formation of low pH fluids, in the Central Colapso wells, has been explained as a post-exploitation process related to the migration of deep magmatic volatile species. Volatiles such as CO₂, S, B, H₂S, Cl, F, etc., react in their way to the surface with aqueous fluids, producing aqueous corrosive species. Few isotopic Boron values are known for Los Humeros (Bernard-Romero and Taran, 2010), they are evidence of the magmatic source feeding the hydrothermal reservoir.

To avoid corrosive fluids, some wells were plug cemented; afterwards neutral fluids in wells discharge were sampled. Later on, once more pH of brines sampled at surface showed lowering of pH. It is very important to note that in the natural state before drilling there is no evidence of acid fluids. In the early stages of production well H-4 had to be shut down and cemented due to strong emanation of H₂S and accelerated corrosion of casings.

Some papers mention the occurrence of two geothermal reservoirs, in this paper we assume the occurrence of a single reservoir in the LHGF (Izquierdo et al., 2008; Gutierrez-Negrin et al., 2010) constrained by geologic structures that favored the formation of acid fluids in wells drilled in the area of the Colapso Central.

Recently, as part of a research project, deep rocks of well H-26 were sampled from the CFE stowage. Expecting to work with a typical altered reservoir rock of andesitic composition, the geological material had a different physical aspect from rocks of the same depth.

The objective of this work is to present physical, chemical and mineralogical data which make evident the interaction of deep rocks with a low pH fluid.

The Los Humeros Geothermal Field

The Los Humeros geothermal field (LHGF) is located 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.

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Geologic Features

Volcanic activity in the Los Humeros area started in the Miocene. It was essentially of fissure type and produced the Andesitic rocks that outcrop at the northeastern part of the Los Humeros caldera and cover the calcareous rocks (Yáñez-García and Casique-Vazquez, 1980 in Gutierrez et al., 2010). Volcanic activity stopped until the Pliocene, when began the volcanism associated to the Mexican Volcanic Belt.

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 overlying volcanic rocks and left a circular weakness zone through which were erupted a series of rhyolitic domes. After these peripheral domes were emplaced, 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 overlying rocks, giving place to the Los Humeros caldera (Yáñez-García and Casique-Vázquez, 1980; Ferriz and Mahood, 1984, in Gutierrez et al., 2010).

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 (op. cit., Gutierrez et al., 2010).

After the Los Potreros collapse, other volcanic eruptions produced several volcanic products including the Arenas and Maztaloja volcanoes, the latter with an explosion crater of 1.7 km in diameter (the Maztaloja 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). 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 most wells, the subsurface lithology can be grouped into four units that are from the top to bottom (Gutiérrez-Negrín, 1982; Viggiano and Robles, 1988).

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.

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). 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).

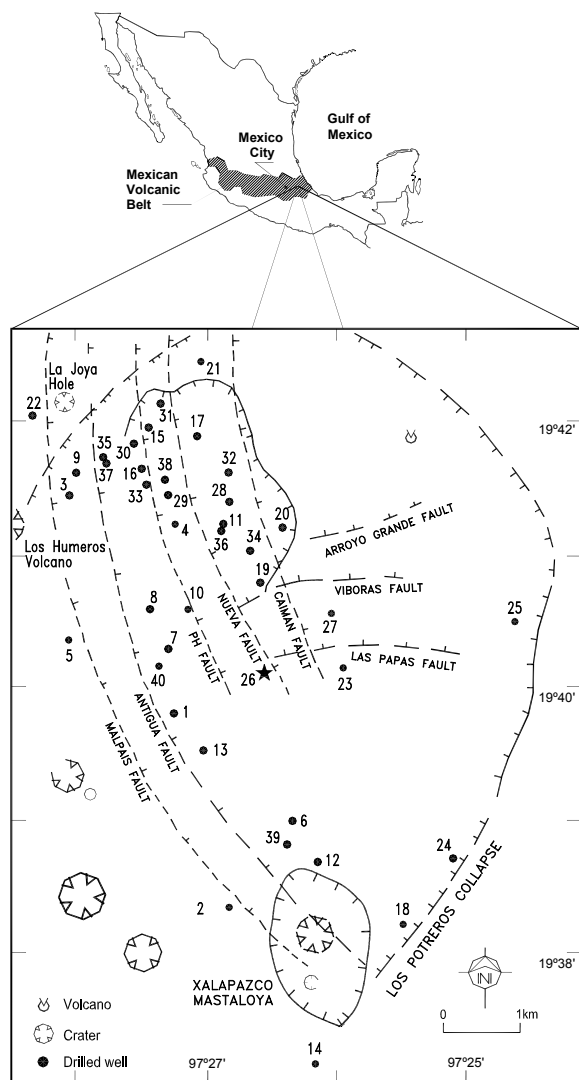


Figure 1. Map of Los Humeros Geothermal field and well location.

Unit 3. Pre-caldera volcanism. It is composed of thick andesitic lava flows with some Tuff intercalations. 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. 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 di-basic 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 throughout 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.

CO₂ is the main gas in the total discharge from most of the wells, followed by H₂S and CH₄ always is in low concentration.

Acid Fluids

In most geothermal systems if an aqueous solution of acid nature occurs, it tends to be neutralized and becomes neutral to 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, sulfate, Mn, Fe and, in consequence they show a chemical imbalance. This is not the case at the LHGF, chemical composition of fluids sampled at the wellhead shows low salinity and the chemical imbalance is not associated to the chemical species mentioned. It rather may be related to the mixture of fluids coming from different strata, corrosion of well casings 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 H₂SO₄. In LHGF evidence of H₂SO₄ is noticed by argillic alteration at the surface. 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 rarely potash alum. No Boron bearing minerals are identified, neither minerals such as lazulite, topaz, rastonite, danburite, gadolinite and zunyite which may indicate the presence of SO₂ and excess of Cl in the fluid discharge of wells.

In the LHGF aqueous fluids are partially neutralized by reaction with wall rocks and hydrothermal minerals such as calcite.

Wells located in the Colapso Central sector present serious corrosion problems, some wells have been closed; to avoid acidity some others have been repaired by placing cement stoppers. (Flores et al., 2010).

Well H-26

Well H-26 was drilled at 2546 m depth, where a maximum temperature of 378 °C was recorded (Viggiano, G. J. C., 1988). Well H-26 is located in the central part of the Los Potreros caldera between well H-1 and well H-23. Well H-1 is the only well that produces high liquid fraction, and has reservoir temperature near to 280 °C. Well H-23 is a deep well (2620 m) with high steam fraction and after one year of production was closed. Temperature logs for this well indicated stabilized temperature higher than 300 °C.

During drilling of well H-26 chemical analysis of water from drilling mud indicated that the concentration of Boron increased from 697 ppm at 2000 m to 839 ppm at 2275 m and decreased as increasing depth (CFE, Internal Report, 1988). At that time it was assumed that the B variation could be an indication of the proximity to the steam supply zone.

Drilling of the well traversed most of the rock sequences previously described. Between 1900 to 2350 m a crystalline vitreous tuff was reported; as increasing depth dacites, andesites and basalts were found. At 2450 m an intrusive of granodioritic composition was reached (Viggiano, 1988).

Despite the proximity of well H-26 to well H-1 its behavior is different from it; the former produces high liquid fraction, the later produced steam and corrosive fluids. Well H-26 and H-23 are the deepest in the field; although high temperatures were recorded both were unproductive. The deeper rocks drilled in well H-26 showed the presence of an intrusive body, of granodioritic composition, which is probably part of the conduction system of deep magmatic fluids.

Mineralogy of Well H-26

Hydrothermal mineralogy, as in most geothermal systems, is associated to the rock and fluid composition. Well cuttings all along the drilled hole indicated the presence of hematite, chlorite, quartz, epidote and pyrite. High intensity of alteration is observed between 1050 and 1590; indicating important water:rock ratio. From 1600 m calcite disappears; between 1940 and 2110 m quartz increases up to 60 % and epidote decreases at its minimum proportion. From 2120 to the bottom of the hole, epidote, pyrite, quartz and biotite are the hydrothermal minerals in drill cuttings.

Even though permeability, circulation lost, temperature and steam were good production indicators, the well was closed because high corrosion on tubes was noted. No production data are available for this well.

Core Sample from Well H-26

In a recent research project a fragment of a core of well H-26 from 2000-2004 m was studied (Figure 2). At first sight the piece of rock did not resemble a typical deep hydrothermally altered andesite (Figure 2). The core of well H-26 can be described as porous mass of rock of cream color, aphanitic, showing small

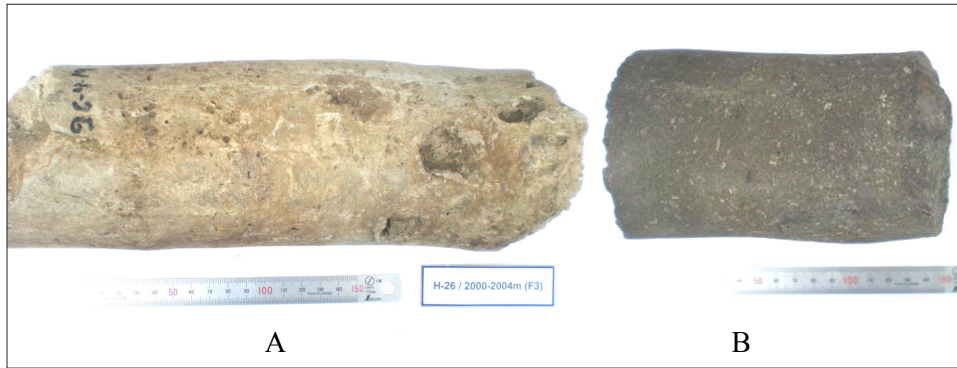


Figure 2. A) Core sample of well H-26. B) Core sample of a deep hydrothermally altered andesite.

fragments of pumicitic aspect and few with fluidal texture. Some cavities are empty some others occupied by tiny crystals of quartz and amorphous material. Also open fractures were observed.

In thin section pilotaxitic texture is observed, subhedral phenocrysts of plagioclase (> 0.5 mm) and quartz crystals are embedded in a micro crystalline quartz matrix. Few crystals of pyroxene and chlorite were recognized. By powder X-ray diffraction quartz, plagioclase and traces of chlorite were identified.

Given the amount of quartz, the rock could be classified as dacite or rhyolite; however the absence potassic minerals and the major element chemistry do not support such classification. In this work it is assumed that the original rock was an andesite attacked by aggressive fluids dissolving primary and hydrothermal minerals living only a porous rock of microcrystalline quartz and relicts of pyroxene, chlorite and pyrite.

Figure 3 presents the comparison between an altered reservoir rock treated with diluted hot HCl (A), and a fragment of the core of well H-26 without any treatment (B). The physical aspect of sample of rock from well H-26 is very similar in color, texture and porous matrix (formed by dissolution of minerals) to the piece of the reservoir rock exposed to hot diluted HCl.

This type of alteration (acid leaching) also causes changes in the physical properties of the rock such as density, porosity, permeability etc.

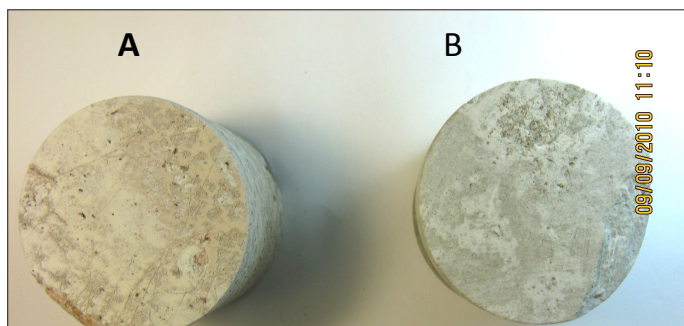


Figure 3. (A) Altered andesitic rock treated with hot diluted HCl. (B) Piece of core from well H-26 as received in the laboratory.

Klinkenberg permeability was measured in a small cylinder of the core of well H-26 before and after treatment with HCl. Measurements indicated the same value for the sample before and after treatment. From these results it is concluded that the rock contains no reactive minerals to be dissolved or leached by the action of the

HCl that may influence changes in permeability. The same cylinder treated with a mud acid mixture significantly increases its permeability. The explanation is that the microcrystalline quartz reacts easily with the mixture of HCl and HF leaving empty spaces.

The chemistry of major elements of the rock before and after being treated with HCl showed no significant changes. With the mud acid mixture, the concentration of SiO_2 decreased significantly.

Recently, Bernard-Romero and Taran, 2010, published isotopic Boron values as an evidence of the magmatic source feeding the hydrothermal reservoir. Although there are few data, they do show two trends that may be associated with two different sources of Boron. One, induced by the intrusive body, affecting well H26 and well H-23, and the other, induced by the magma chamber affecting wells located in the Colapso Central.

These sources of acid fluids do not affect the fluids of all the drilled wells in the field because these sources seem to be restricted locally by geological structures as seen in Figure 1.

Conclusions

Core of well H-26 from 2000 m depth has naturally affected by acid fluids. The silicification of the core is the result of an alteration process (leaching) caused by acid fluids.

The absence of primary and secondary minerals in the studied core is an indication of the leaching process promoted by acid fluids. The porous rock mass is the remnant of an andesitic rock that once interacted with an aqueous fluid.

Mineralogical, chemical and physical data support the assumption of the occurrence of low pH fluids in a particular deep zone of the LHGF.

Acidity in LHGF is likely to have two sources one induced by the intrusive body, affecting well H26 and well H-23 and the other, induced by the magma chamber affecting wells located in the Colapso Central.

Additional work has to be done in order to support the assumptions presented in this work.

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