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CASE HISTORY OF LOS AZUFRES – CONCEPTUAL MODELLING IN A MEXICAN GEOTHERMAL FIELD

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ABSTRACT

The conceptual model provides a descriptive representation of a geothermal system, based on geological, geophysical and geochemical information and the analysis of data and measurements made in the drilled wells in order to define the main reservoir characteristics such as shape, limits, dimensions, probable recharge and discharge areas and temperature and pressure distribution.

In this paper, the conceptual model of Los Azufres geothermal wells is presented. This geothermal field is a complex formed by extruding a series of lavas with an extension of 20 km^2, of basaltic and acidic quaternary age composition on a basement of tertiary andesitic composition. The unit Mil Cumbres andesite is the one that contains the reservoir while the unit Agua Fria rhyolite operates locally as a cap rock. The hydrothermal alteration is typical of a high-temperature geothermal system. Faulting has occurred along three principal trends NW-SE, NE-SW and the youngest E-W. The chemical composition of the fluid is sodium chloride type. The fluid seem to flow vertical with limited lateral movement, a high resistivity rock body existing at the central of the field, separates the geothermal reservoir as the north and the south sectors. The production zones of the wells in most of the cases are located to intercept a zone associated with a permeable structure. The thermodynamic state is conceptualized as a reservoir with three different areas, the deepest one composed of compress liquid, the middle one of two phases layer of liquid dominated reservoir and the shallow one of two phases steam dominated reservoir.

1. INTRODUCTION

Conceptual models are based on the integration of data from different disciplines to explain in our case a geothermal reservoir, in other words is a descriptive representation of a geothermal system based on the geological, geophysical and geochemical surface and data analysis and measurements made in boreholes.

The considerable amount of investigation that has been conducted in the Los Azufres field, combined with the extensive information available from the large number of wells drilled, has allowed a reliable model of the geothermal reservoir to be developed in order to create a numerical model. This conceptual model is described and discussed in the sections that follow.

1.1 The Los Azufres geothermal field

Los Azufres geothermal system is located in the State of Michoacán to 80 km east of the city of Morelia and 16 km northwest of Ciudad Hidalgo, this geothermal field was explored in the mid 70 and since 1982 it has been in development, in the natural state was classified as conventional liquid-dominated high temperature system but during the long term of exploitation several thermodynamic studies have shown that the reservoir has three zones: dominant vapour in the upper reservoir, liquid saturation in the middle and liquid compressed in the bottom part of the reservoir. This field is located at an altitude above sea level ranging from 2500 to 3000 m, surrounded by valleys.

At the present time Los Azufres geothermal field have 43 production wells, 6 injections wells producing 14.7 million tonnes of vapour and generating 185 MW from 1 condensing unit of 50 MW, 4 condensing units of 25 MW each, 7 back-pressure units of 5 Mw each. In the present time there is under construction one 50 MW condensing unit in the northern part of the field that will replace 4 unit of 5 MW for a total electric generation of 215 MW.

1.2 Previous work

Several geological, geochemical and geophysical studies have been conducted since 1975, being in 1984 when the first geothermal conceptual model of the field was prepared, revealing the volume, reserves and reservoir boundaries, based on the above studies and complementary data produced from wells drilled to date (De la Cruz, 1984). In February 1987, new exploration data was available and an update of the conceptual model was done (Lira, H., 1987), in this work, configurations of isotherms were performed every 50 °C from the 150 °C to 300 °C, for elevations of 500 masl to 2500 masl, from the interpolation and extrapolation of the stabilized temperatures of 52 wells. Also, the configuration of the top of the epidote was conducted in the same levels as the isotherms, taking into account the 10% lower limit of the presence of epidote. And finally, the boundaries of the reservoir were defined taking into account the isotherm of 225 °C, the minimum resistive of geothermal interest, epidote settings and production wells.

Another redefinition of the conceptual mode was made in 1996 but only in the northern-east part of the field (Flores, et, al., 1996), while the conceptual model of the south part was made in 1997 and it mentioned that the reservoir is made up of three lithological units (andesite, dacite and rhyolite), rhyolite is functioning as a caprock, also mention that the production zone in most cases appears to intersect one permeable zone associated to the E-W structure or a influence zone between the interval from the top of the epidote and amphibole. It should be clear that the overall thickness was calculated by averaging the calculation from the correlation of the obtained permeable zones and the difference between the top of the amphibole and epidote. In addition it is mentioned that the fluid is spread vertically through faults and the direction of the preferential fluid flow is NW-SE according to plan distribution of total gas, ratio of CO_2/H_2S, isotopy, pressure and temperature.

In 2003 CFE hired the services of GeothermEx, Inc. to update the conceptual and numerical model of the geothermal field of Los Azufres and in 2007 West Japan Engineering Consultants, Inc. (West JEC) and Japan Bank for International Cooperation (JBIC) reinterpret the conceptual model in the feasibility study of the Los Azufres III geothermal energy expansion project which is the most recently reinterpretation of the model with no big changes from the last one.

2. SURFACE MANIFESTATIONS

The Los Azufres field extends over a considerable area (in excess of 20 km2) in the highland area east of Morelia in the state of Michoacán, within the Mexican Volcanic Belt. Manifestations of geothermal activity are distributed widely within and around the highlands (Figure 1); however, the principal manifestations are clustered within the field itself, and particularly within the areas that deep drilling has revealed to be the northern and southern sectors of the productive geothermal field.

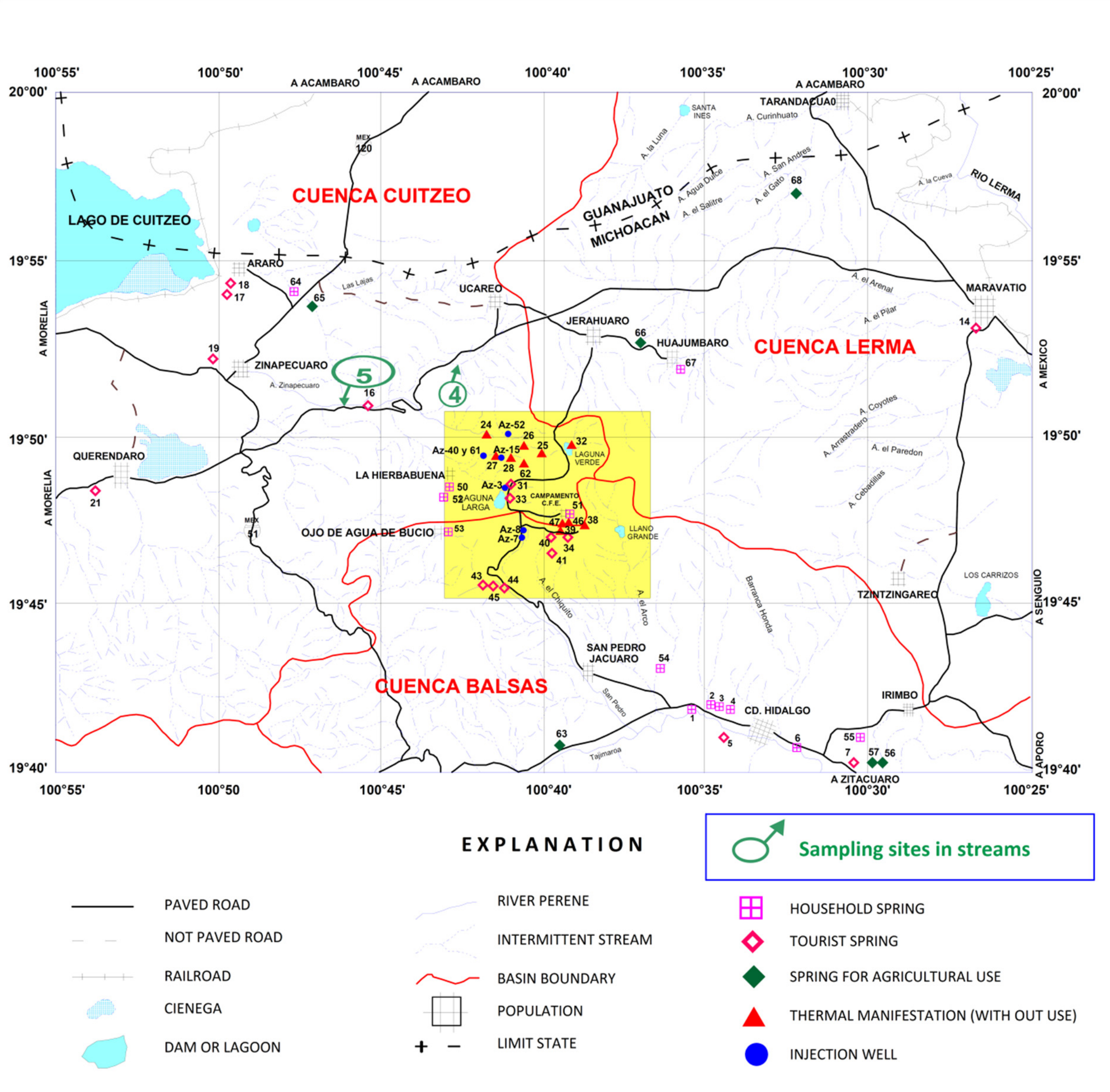

FIGURE 1: Location of the Los Azufres geothermal field and the surface manifestation

The majority of the thermal manifestations are described as hot springs of acid-sulfate composition, with pH lower than 4.0, and often with temperatures near boiling (Tello and Suárez, 2000). The composition of the waters indicates an origin for these springs from steam boiled from the geothermal reservoir, which has then mixed with oxidizing groundwater to form the acidic discharge. This is a common phenomenon in high-temperature, volcanic-hosted geothermal systems located in mountainous terrain.

Some springs located around the periphery of the field are of sodium chloride type, indicating a more direct discharge of liquid water from the reservoir to the surface. Still other springs are of sodium bicarbonate type, with low geothermometer temperatures, indicating a significant degree of mixing with cooler waters or other interaction with the shallow environment. Again, these types of manifestations are typical of volcanic-hosted geothermal systems in which the reservoir fluid is fundamentally neutral sodium-chloride water.

Many, though not all, of the superficial manifestations are located along the mapped traces of major faults that transect the field. Leakage of steam and water from the geothermal reservoir toward the surface may occur principally along faults, but the surface locations could be controlled by a combination of structure and lithostratigraphy (permeable volcanic formations), with the interaction of the two creating a complex arrangement of thermal discharges. The manifestations provide a certain amount of evidence regarding patterns of flow within and from the geothermal reservoir; this is discussed further in subsequent sections (GeothermEx, 2003).

3. GEOLOGY

The geology of the Los Azufres field has been studied in exhaustive detail, both by means of geologic mapping and other studies conducted at the surface, and by analysis of drill cuttings, cores and other data from the numerous deep wells in the field. This section summarizes the geologic characteristics of the field that are pertinent to the development of a reliable numerical model.

3.1 Stratigraphy

Los Azufres geothermal field is one of several Pleistocene silicic volcanic zones with geothermal systems in the Trans Mexican Volcanic Belt (TMVB). The volcanic rocks in Los Azufres geothermal field are mainly divided into four principal units.

Mil Cumbres Andesitic Unit – This unit occurs throughout the field, and is the thickest unit of an average of 2700 m, accounting for all of the reservoir rocks and extending below sea level. This volcanic sequence comprising andesitic rocks with some paleo-soil layers, basaltic rocks and volcanic agglomerates of 18 to 1.0 My age forms local basement in the field.

Agua Fría Rhyolite Unit – This unit is a silicic sequence up to 1,000 m thick and overlies the Mil Cumbres Unit, and consists mainly of a spherulitic rhyolite lava with ages between 1 and 0.15 My. It is present at shallow levels, often outcropping, and is found mainly in the southern and central part of the field.

Dacita Tejamaniles – These young lavas occur locally in the southern sector of the field, and overlie the Agua Fría Ryolite.

Tuff (pumice flow deposits) – This unit is considered to include a variety of young, superficial pyroclastics deposits, which have originated from relatively young volcanic activity in the vicinity of the field.

3.2 Structure

Faulting in the Los Azufres field has occurred along three principal trends. From youngest to oldest, these trends are NW (or NNW)-SSE, NE-SW, and E-W. All three trends are represented by major faults that have been mapped within or near the field. The E-W trend appears to be the most significant, exerting a strong influence on the geomorphological characteristics of the area, as well as on certain characteristics of the geothermal system. Most of the fault systems consist mainly of normal faults with steeply dipping.

The fault system in the south sector with E-W trending are San Alejo, Agua Fría, Puentecillas, Tejamaniles, Los Azufres y El Chinapo faults and in the north sector are Laguna Larga, El Chino, Espinazo del Diablo, Coyotes, Maritato y La Cumbre faults. This last two faults have left-lateral strike-slip, which accompanies en echelon segments. The NE-SW trending faults in the south are El Vampiro, El Viejon and Agua Ceniza faults and the ones that occur in the north are Nopalito and

Dorado faults. And The NNW-SSE trending faults (La Presa, Laguna Verde and Río Agrio) are located in the north zone (Figure 2).

Concealed NNW-SSE trending fault is supposed to exist in the field, which probably extends to the basement rocks, based on topographical analysis and geophysical data analysis. Topographic features of NNW-SSE trending fractures are highly dissected and are cut by E-W trending faults system. The NNW-SSE trending fractures, therefore, are supposed to be older systems compared with those of E-W trending faults systems (West JEC, 2007).

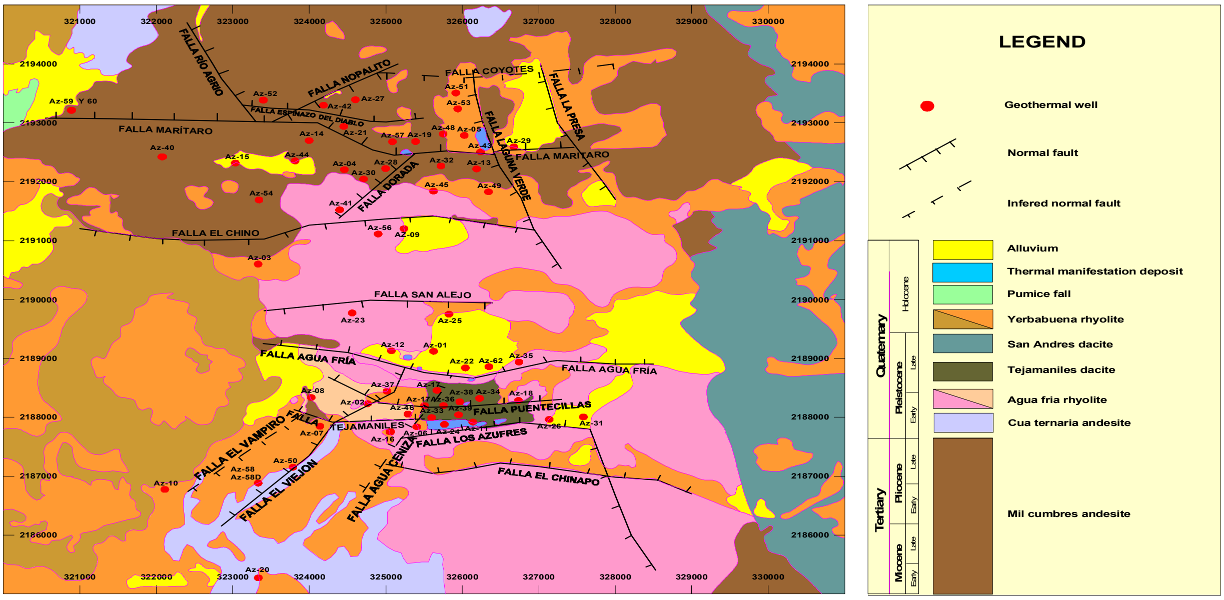

FIGURE 2: Surface geology and fault location of Los Azufres geothermal field

3.3 Hydrothermal alteration

Hydrothermal alteration in the Los Azufres field is fairly typical for a high-temperature, volcanic-hosted geothermal system (Figure 3). Secondary minerals observed in drill cuttings include clay minerals, calcite, chlorite, pyrite, quartz, epidote, hematite and other oxides, and hydrothermal amphibole. Several zones of different hydrothermal mineral assemblages have been identified; these are distinguished principally on the basis of the first appearance (as a function of depth in the well) of epidote and hydrothermal amphibole. The appearance of epidote has been found to correlate with formation temperatures of about 250°C, whereas the first appearance of amphibole tends to coincide with temperatures near 300°C. The surface of first appearance of epidote has also been correlated with the top of the productive reservoir zone, while the first appearance of amphibole has been inferred to correspond with the base of the productive reservoir.

3.4 Impermeable zone and cap rock

One of the important elements of the geothermal reservoir is the cap rock which prevents cold groundwater from invading into the high temperature reservoir. In the depths shallower than 500 – 700 m, clay alterated minerals such as smectite, zeolite and chlorite are identified in geological analysis of production wells. Arigillic alteration zone consists of kaolinite, alunite, sulfer and quartz are also identified. In general, clay mineral such as smectite and zeolite are formed under the circumstances below the temperatures ranging approximately 70 to 200 °C. Therefore, it is considered that the formation at the depths shallower than 500 – 700 m acts as a cap rock of the geothermal system due to clay alterations that are generally impermeable.

The upper limit of the cap rock in the north sector is probably shallower than that of the south sector. At depths of 2,400 – 2,600 masl the cap rock is widely developed in the main productive zone in both the north and the south sectors. Around the wells Az-41 to Az-9 in the north sector, the depth of the lower limit of cap rock is relatively shallow as well as the depth of the upper limit of epidote. This facts indicate that higher temperature zone may exist at shallower depths and an up-flow zone of geothermal fluids may also be formed around there. In the south sector, the depth of lower limit of cap rock deepens toward the west. This indicates that the subsurface temperature decreases toward the west.

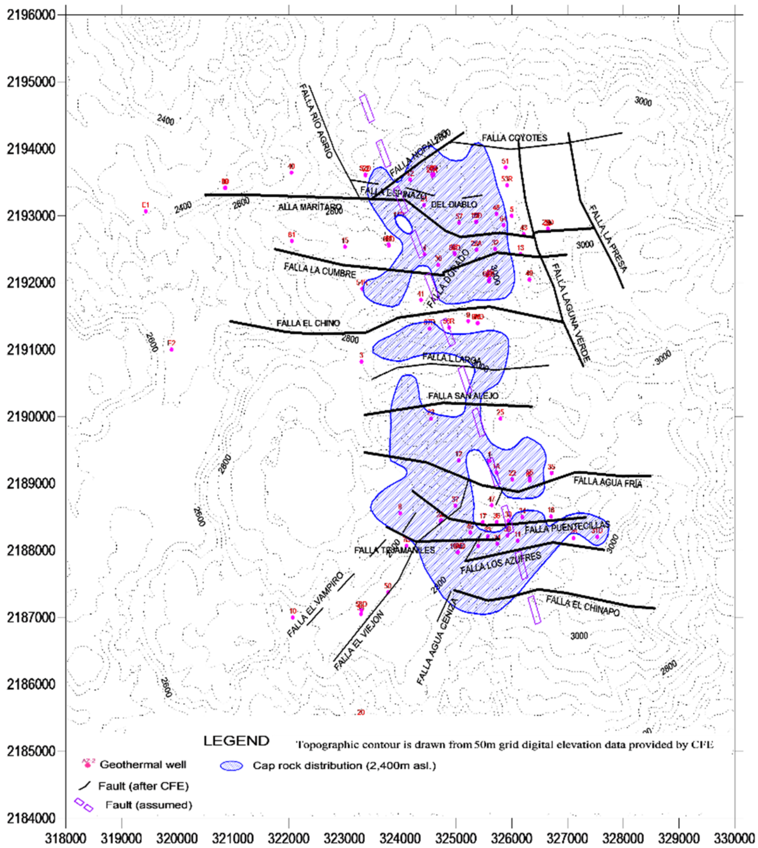

FIGURE 3: Cap rock distribution map (2,450 masl)

In the south sector, the distribution of the cap rock disappears around El Chinapo at the south. In the north sector, the distribution of the cap rock disappears around the Laguna Verde fault at the east, and around both the Coyotes and the Nopalito faults at the north. In the Central zone the cap rock is relatively weak as well as the subsurface manifestations. This limitations seem to represent the distribution of the geothermal system in the field.

4. GEOCHEMESTRY

The geochemistry of the Los Azufres system has been interpreted from analyses of numerous samples of fluids (water and steam) from the various deep wells in the field, as well as analyses of discharges from surface manifestations.

4.1 Fluid characteristics

The water and steam from all the wells in The Los Azufres are of neutral sodium-chloride composition typical of geothermal fluids in the world. So far, it hasn´t been reported acidic waters in the reservoir. Chloride is dominant among major anions and although these vary considerably from one well to another, the water concentrations separated at atmospheric pressure is around 2,500 – 4,000 ppm at the initial stage of exploitation. This reflect in part the variable distribution of phases within the reservoir, particularly in the southern sector.

In the case of the non-condensable gas (NCG) the concentration in reservoir liquid may be as low as 1% by weight or less, while NCG concentrations in the steam phase range between 2% and 8% by weight (Suarez, et al., 2000). Carbon dioxide (CO_2) is the main component of NCG and its content is over 90 mole% in NCG at most wells. Other NCG that are measured but in lower concentrations are H_2S (0.5 – 18 mole%), N_2, NH_3, H_2, CH_4, Ar and He. Gas concentrations in the southern sector have always been larger than in the north sector. It should be mentioned that the chemical geothermometry of waters produced from the reservoir zone is generally consistent with temperatures interpreted from measured downhole temperature profiles, with maximum geothermometer temperatures well in excess of 300°C.

4.2 Origin of the fluid

At the beginning of the project (1980 – 1987) measurements of isotopic composition of the fluid from the wells indicate a combination of process water – rock interaction and admixing of magmatic water (including the andesitic water) with meteoric water. The meteoric water that is main constituent of reservoir fluid is believed to be fossil meteoric water infiltrated into subsurface during pre-historic time.

One of the important characteristics of the well fluids in Los Azufres is that show high concentrations of boron in comparison to other geothermal fields, this could be interpreted by the interaction of deep fluid with sedimentary rock with a high content of boron. And although none of the wells intercepted sedimentary rock (including the well Az-44 which is the deepest with 3,500 m), the regional basement at Los Azufres is built up by metamorphosed sediments. Relatively high NH_3 content up to 3.5 mole% in NCG of the well steams also indicates the contribution of sedimentary rocks to the reservoir fluids.

4.3 Fluid flow pattern

The parental fluid is found at a great depth within or over the metamorphic and sedimentary basement rocks and even though no one knows for sure what geologic structure controls the flow of fluid, but there are tectonic history that suggest that high permeable zones associated with faults control fluid flow. The NNW-SSE trending faults assumed by geological and geophysical data is one possibility for controlling the northwestward regional fluid flow of parental fluid at deeper depth.

The parental fluid ascends through the high permeable zones developed along the faults and stored in andesitic rocks. The high resistivity rock body existing at the central part of the field, separates the geothermal reservoir as the north and south sectors (Figure 4). The main direction of movement of the flow in both areas at intermediate depths appears to be vertical with very limited lateral movement. The ascending hot fluid yield convective circulation systems beneath the cap rock in both sectors. The fluids reaching shallower part of the reservoir boil and provide two–phases or vapor dominated reservoir. This is more significant in the south sector than in the north. Partial steam condensation at the shallowest part of the reservoir in the south sector yields gas rich zones.

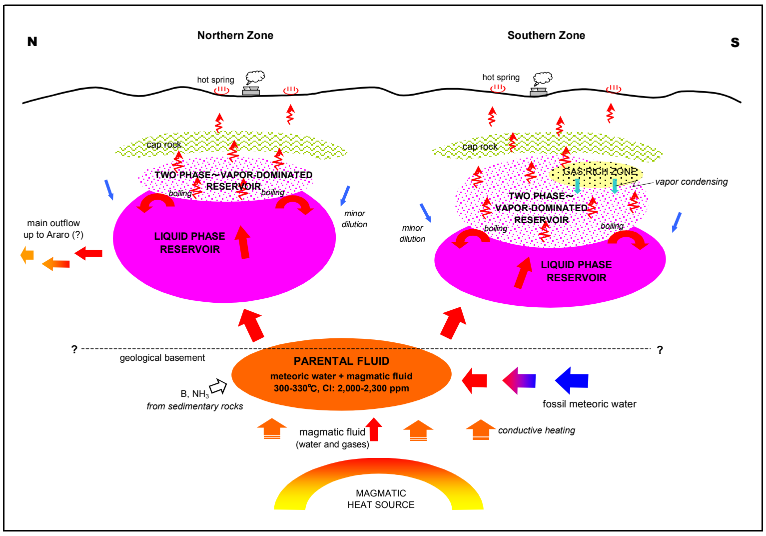

FIGURE 4: Fluid flow model of Los Azufres reservoir

Outflows are limited compared with many geothermal systems, however we can consider the Araro hydrothermal system is a part of outflow from Los Azufres system even though is 20 km NW away. Also another important outflow can be located in the SW in the north sector of the field; nevertheless, it could be present other unidentified flows.

5. GEOPHYSICS

In Los Azufres there have been various geophysical studies such as gravimetry, magnetometry, passive seismic and geoelectrical prospecting, including vertical electric soundings (VES) and a magnetotelluric survey of part of the field. Of these methods, the geoelectrical survey have been of the most direct use for delineating the productive geothermal field.

Maps of apparent resistivity for progressive electrode spacing show that, in the shallow part of the field, zones of low resistivity are concentrated within the central part of the northern and southern sectors of the field and a high resistivity in the central part of the field (Figure 5). With increasing depth, these zone expand outward, forming a more generalized conductive layer joining both sectors of the field. This is a very common pattern, which most often reflects the distribution of conductive hydrothermal minerals near and above the top of the reservoir zone. In general there is a good correlation between the position of the low resistivity zone and the position of the geothermal reservoir, confirmed by drilling.

The distribution of the low resistivity zone has been used as a means of delineating the extent of the geothermal reservoir, however, the use of low resistivity cutoff to delineate the reservoir at deeper levels therefore runs a risk of overestimating the area of the reservoir. Once a field has been drilled as extensively as Los Azufres, the distribution of observed temperature and well productivity is likely to be a more reliable guide to the extent of the productive geothermal reservoir.

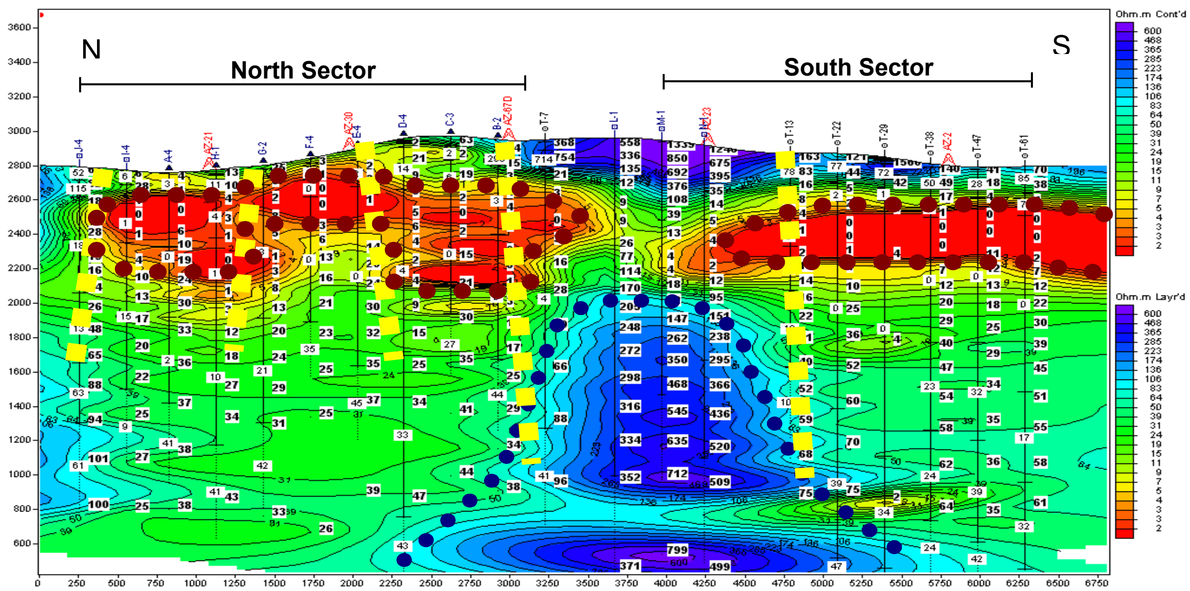

FIGURE 5: Resistivity section along N-S direction in Los Azufres geothermal field

In addition, Local Bouguer high anomaly and high total magnetic values in the field suggest the possibility of existence of the magnetic intrusion under the field.

6. RESERVOIR ENGINEERING

Reservoir temperature and pressure as well as the permeability distribution are fundamental elements of any physical model of a geothermal system. The distribution of subsurface temperature is a critical parameter used to establish (by matching) the initial-state model of the field. A good interpretation of pressure distribution can be important for understanding the thermodynamic characteristics of the reservoir (particularly the distribution of fluid phases), as well as the hydrodynamic aspects of the system in order to establish the production and injection strategies in the field to maximize sustainable power generation.

6.1 Lost circulation and permeable zones

Reservoir permeability in volcanic-hosted geothermal systems is, in nearly all cases, a product of fractured competent rocks, rather than a result of rock porosity. Fracturing can result from a variety of mechanisms, including original rock emplacement (e.g. fracturing of a lava flow), rupture along or adjacent to major faults, more generalized tectonic stress (not necessarily associated with major fault zones), and hydraulic forces.

Zones of higher permeability in the Los Azufres reservoir has been interpreted to be localized, at least in large part, along major faults, particularly of the E-W-trending set, or their zones of influence. Also temperature pattern correlation indicates a fairly rapid drop in permeability with distance to the south and to the west of the zone of highest temperature in the southern sector. Because the reservoir appears to terminate rather than extending along the trends of the major mapped faults, the possibility could be considered that several of the major faults act as permeability barriers that serve to localize the reservoir.

Lost circulation zones observed during well drilling are mainly within the andesitic rocks. The most of lost circulation are correlated with the fault locations (Figure 6) which are inferred from geological consideration and other information such as result of PTS loggings.

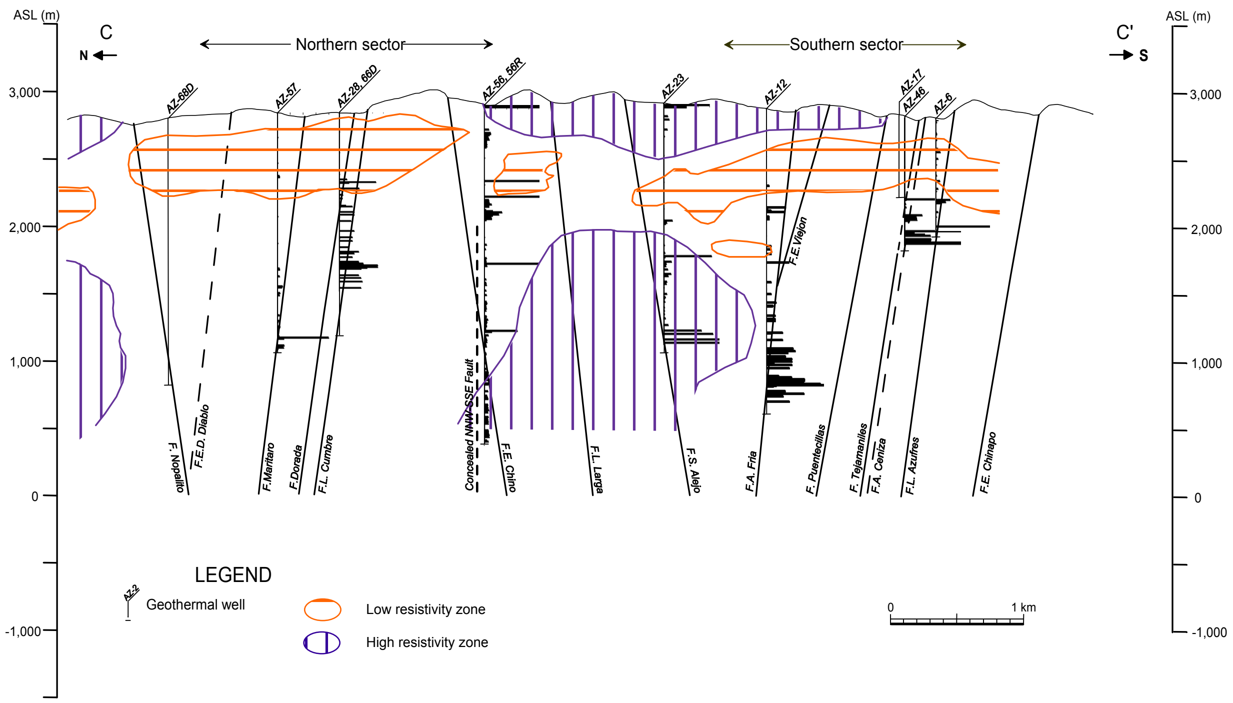

FIGURE 6: Lost circulations

6.2 Subsurface temperature and pressure

In Los Azufres many wells have been drilled which allows us to understand with certainty subsurface temperatures, some important aspect that reveal the temperature distribution are:

- Two distinct zones of high temperatures are evident: one corresponding to the north sector of the field, and the other to the south sector. In both zones, temperatures increase steadily with depth, reaching more than 320°C at an elevation of 700 masl in the hottest part of both sectors (Figure 7). The maximum measurement temperature is 347 °C at 250 masl of well Az-9.

- The horizontal position of the zone of highest temperatures in each sector changes only slightly with changes in depth. The northern hot zone is elongated slightly along a northeastward trend. The southern hot zone has an eastward to ENE elongation; its eastern limit has not been defined by drilling. The temperature distribution does not indicate the presence of extensive zone of outflow.

- The two high-temperature zones are distinct at most levels, though the distinction becomes smaller with increasing depth, so that, at the deepest levels for which data are available, there is uncertainty as to whether the two sectors of the field constitute separate hot zones. It must also be noted that the distinction of the two hot zones is based mainly on temperatures observed in 3 wells (AZ-12, AZ-23 and AZ-25), which lie in between the northern and southern sectors. In both sectors measured temperature reaches 200 °C at 2,200 masl on the other hand, the central part between them, the temperature is around 150 °C at the same elevation.

- In the north sector, characterized by liquid dominated reservoir, the average reservoir temperature is reported as 300 ºC at the elevation between 200 and 2,200 masl. In the south sector, the two-phase steam-dominated reservoir at the elevation between 1,800 and 2,600 masl indicates an average temperature of 270 ºC. The temperature of two-phase liquid-dominated reservoir at elevations between 400 and 1,800 masl has been reported to be 300 °C. An average temperature of the deep liquid reservoir at the elevation between –50 and 400 masl is reported 350 ºC.

- The iso-therm counters at 1800 masl shows in the north sector an area hotter than 250 °C is identified in between La Cumbre and Chino faults, and it is limited by Dorada fault at the west and by the Laguna Verde at the east. In the south sector an area hotter than 250 °C is identified in between Agua Fria and Los Azufres fault, and it is limited by El Viejon fault at the west.

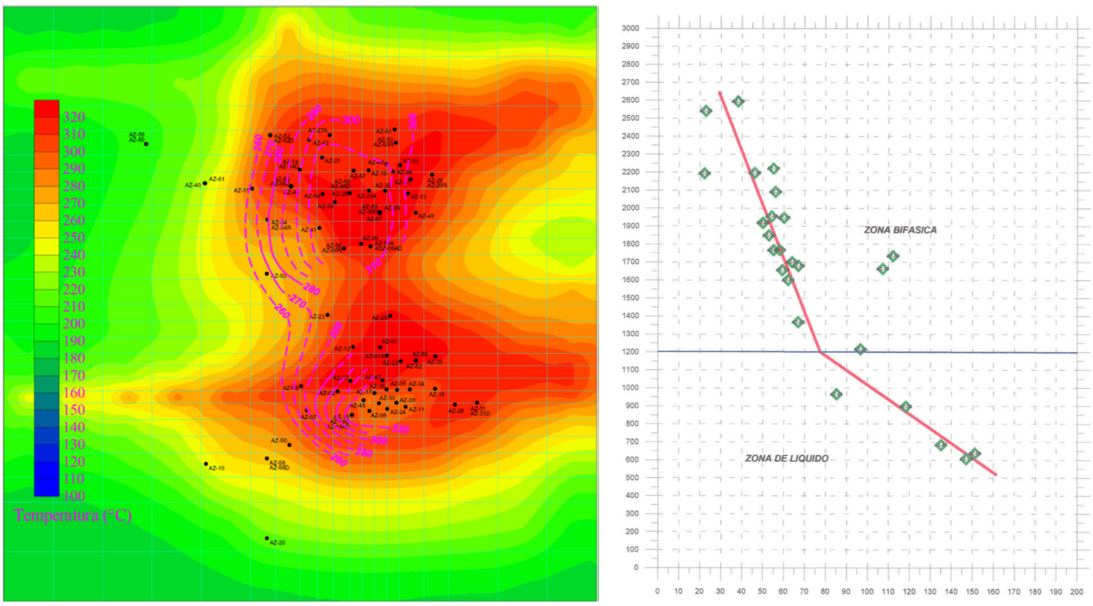

FIGURE 7: Distribution temperature (700 masl) and pressure profile

Liquid geothermometry using the NaKCa and silica (quartz) temperatures indicate the reservoir fluid temperature from 250 to 330 °C for initial stage. Gas chemical temperatures of TCO_2/Ar and TH_2/Ar for the well gases are relatively scattered within a range from 200 to 350 °C. The parental fluid assumed at deeper depth is estimated as 300-330 °C.

Initial static bottomhole pressures in wells of varying depth provide a useful indication of the distribution of initial static pressures in the geothermal system. In the southern sector, there is a clear transition from a single-phase-liquid pressure gradient below an elevation of about 1,200 masl, to a lesser pressure gradient above this level (Figure 7); this indicates the presence of two-phase conditions in the upper zone, which (based on the overall evidence) transitions to a steam-dominated zone in the shallowest part of the reservoir. In the northern sector, no such distinct transition of pressure gradient is observed, indicating that the reservoir in the northern sector was initially single-phase throughout, except perhaps in its shallowest part.

6.3 Production and reinjection

At present, more than 43 production wells are producing steam and connected to the power plants. The fluid enthalpy is relatively high for most of the production wells, while some of the production wells are producing only steam but without water, so that the fluid enthalpy is very high in these wells. Among the wells that show medium enthalpy, the increasing trend of the enthalpy value can be observed in wells AZ-4, AZ-5, AZ-13, AZ-18, AZ-26, AZ-28, AZ-43 etc.

The reinjection capacity at present is around 2000 t/h, there are 6 wells accepting separated water and condensed water. The total reinjection amount is around 700-800 t/h. The capacity of existing reinjection well is much larger than actual reinjection amount, which means additional drilling of reinjection well is not necessary at the moment (West JEC, et al,. 2007).

7. CONCLUSIONS (GEOTHERMAL RESERVOIR CONCEPTUAL MODEL)

The Los Azufres geothermal reservoir includes a broad zone, at least 20 km2 in extent, in which the geothermal fluids are stored in high permeable zones, associated to faults in andesitic rocks accompanied with rhyolites that act as cap rock and are formed at depths between 500 – 700 m from subsurface, and mainly due to clay alteration zone. This cap rock prevents cold groundwater from infiltrated into the high temperature reservoir.

The heat source of the system is presumably related to young volcanic activity of the area. Heat may be supplied to the system by a cooling magma chamber or intrusive body of rock; however, the precise characteristics of such a source cannot be determined from available data even though a local Bouguer high anomaly and high total magnetic values in the field suggest the possibility of existence of the magnetic intrusion under the field. Similarly, the nature of the source of upwelling fluids feeding the system cannot be determined with complete precision. Based on the temperature distribution conclude that the high temperature fluid (>320°C) is caused mainly by the meteoric water circulation at deep levels that enter to the system and mix with magmatic water. The concealed NNW-SSE trending faults probably extend to the basement rocks and are supposed to control the deep geothermal fluid flow supply and discharge of fluids towards Araro; however, other unidentified outflows may be present.

The geothermal reservoir is divided in two productive zones, the north and the south sectors, this two sector are separated by a low permeability zone which shows high resistivity characteristics. The production zones are located where the wells intersects to the E-W trend faults, and within a depth interval defined approximately between the first appearance of epidote and the top of the amphibole (Perez, 2001). In the south sector, the geothermal fluids at depth are considered to be up-flowing around the conjunction trending faults (Puentecillas, Tejamaniles, Los Azufres) and NE-SW trending fault (Agua Ceniza) and in the north sector, the geothermal fluids seem to be up-flowing around El

Chino, La Cumbre and Dorada faults and spreading along high permeable zones defined by E-W trending faults. Around wells Az-41 and Az-9 the geothermal fluids seem to be ascending to shallower levels. Presence of fracture zone (en echelon fractures) caused by strike slip of La Cumbre and Maritaro faults is assumed to exist and probably this fracture zone controls the ascension and spread of geothermal fluid (West JEC, et al., 2007).

In consideration of the faulting geometry, cap rock development, subsurface temperature etc., the productive area of the reservoir extent in the north sector is delineated by Laguna Verde fault at the east, and by Coyotes and Nopalito faults at the north. In the south sector, the reservoir extent is bounded by El Chinapo at the south and El Viejon at the west. In the central zone, between San Alejo and Agua Fria faults where the permeability and subsurface temperatures in volcanic rocks are estimated to be lower compared with those of the north and the south sectors.

Figure 8 shows a geothermal conceptual model in a plane view and Figure 9 shows a cross section of the conceptual model. Having a conceptual model in such a detail has allowed a proper management of the production and injection strategy, to maximize power output in a sustainable way. It is also important to be able to locate well makeup wells and also as an input for numerical modeling, in order to be able to check changes in the strategies, well location and effects in the reservoir if an expansion plan is advisable or not.

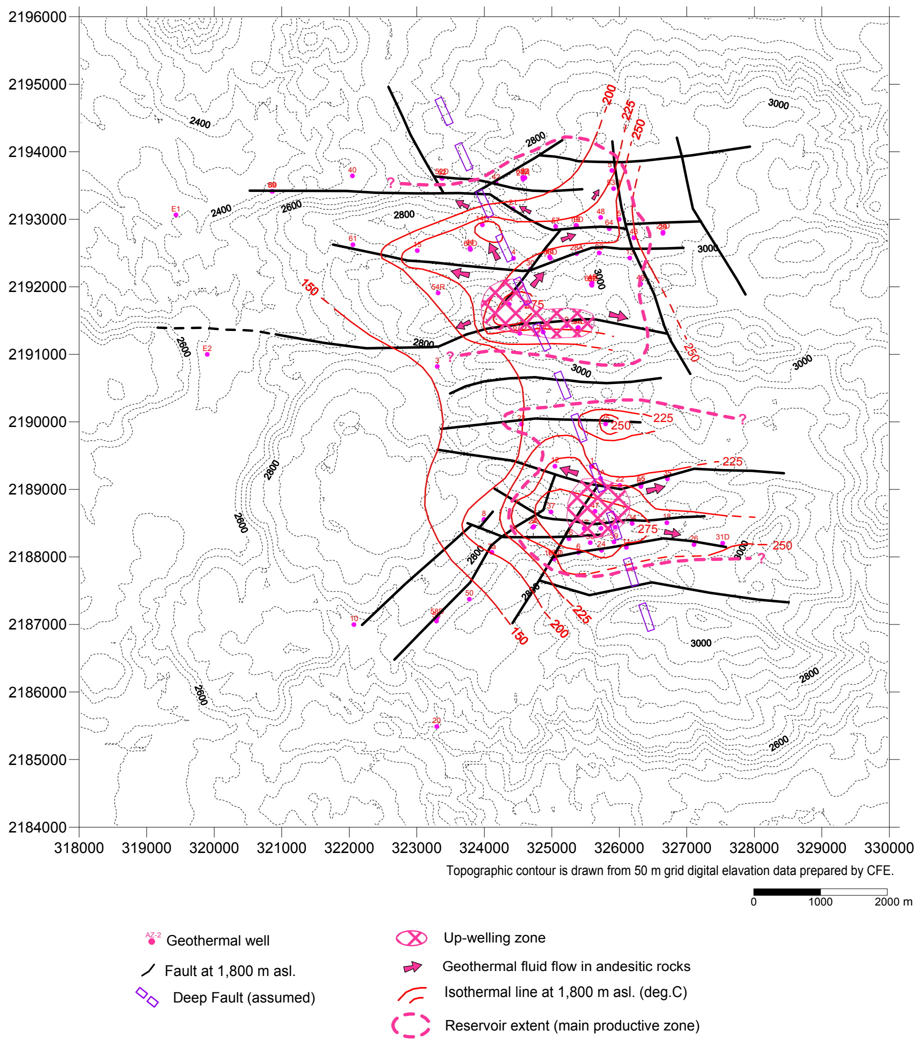

FIGURE 8: Geothermal conceptual model (plane view)

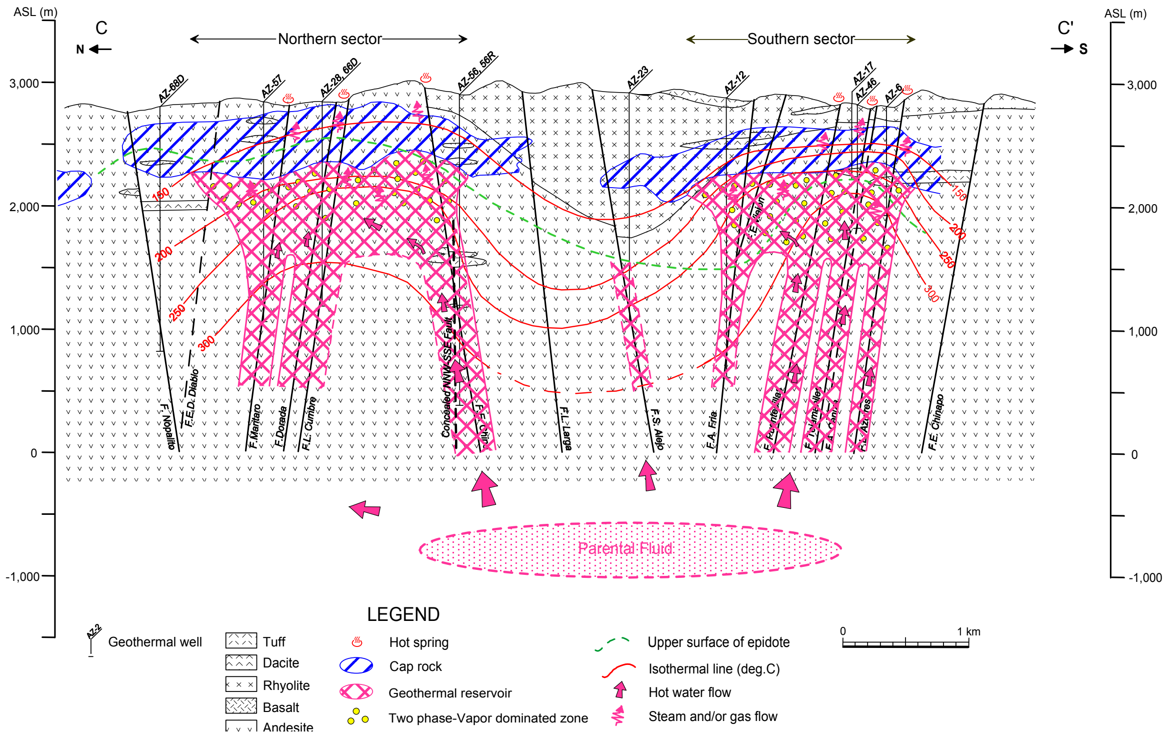

FIGURE 9: Geothermal conceptual model (cross section)

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