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Identification of communicated intervals between wellbore and reservoir applied in a Mexican geothermal system

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ABSTRACT

Primary porosity and permeability are some of the physical characteristics which seem to be scarce in geothermal reservoirs, due to their volcanic nature, influencing conditions reduction for communication between wellbore and the reservoir. Under this circumstance, one of the fluid flow ways between the reservoir and the wellbore is through permeability caused by fissures between blocks rock of the geological structures. These communication intervals with reservoirs had been found non-continuous in the majority of geothermal fields due to heterogeneity of rock formation. Besides, sometimes not all of these communicated intervals with the reservoir provide geothermal fluid with thermodynamic characteristics, only represent permeability, but do not a feed zone. In this work are shown analysis of temperature and pressure profiles from measurements taken at similar conditions of repose times, in wells grouped in a geological structural block in Los Humeros Mexican geothermal field. The analysis carried out was designed to take into account abnormal behaviors of both thermodynamic parameters, correlated with respective gradients and with the lithological formation of each well. The methodology applied in such analysis allows identifying communicated intervals in the well with the reservoir, besides through correlation it was possible to select which intervals are acting as feed zone. Practical application for identification communicated intervals type with the reservoir is focused for selecting, in case of producer wells, the characteristics of theirs production liners (slotted or smooth). By another hand, if there are no production characteristics, could be chosen for adapting it, for reinjection.

1. INTRODUCTION

Distribution at subsurface and at deep of geological structures is one of the factors for permeability appearance in geothermal reservoirs, which majority are located in volcanic systems. Heterogeneity of volcanic systems is one of their characteristics, which does not guarantees continuity of formation strata through the reservoir, also including hydrocarbon fractured systems. In geothermal systems, tectonic of volcanic formations is characterized by absence of primary porosity and low permeability, which occurs in fissures between blocks of the structures. During drilling of geothermal wells, it has been found existence of abnormal behaviors in measured pressure and temperature, such as variation in gradients as depth function.

Structures (fractures and faults) play a key role in localizing permeability (commonly referred to as secondary permeability) in intermediate temperature to high-temperature convective geothermal systems (Glynn-Morris et al., 2011). The importance of faults and fracture systems is that they serve most fundamental level, as channels for geothermal fluids, such as occurs in volcanic rock formation (Jolie et al., 2019). Permeability of structures spaces is a main influence factor for controlling the productivity of geothermal wells as they form the paths for fluid movement in the system either as upflow zones or recharge zones (Bauer et al., 2019).

Through development of reservoir engineering, several techniques could be used to map out the structures influencing reservoir behavior. These include, during exploration stage, since visual surface observations for geological faults and fractures location, as mineralogical alteration. During drilling operation, these techniques include the determination of water loss zones, temperature and pressure profiles measured by logs, transient pressure tests and in some cases, conducting acoustic televiewer logs of the wellbore (Tajul et al., 2020). However televiewer logs cannot be used in geothermal wells by its resistance thermal capacity is for temperatures lower 200 °C.

Due to high temperature and volcanic characteristic of geothermal systems, in this study thermodynamic measurements taken with mechanical tools were used in place of those electric and electronic. Finding besides, that these intervals are reduced to small lengths, therefore in the best cases; each one contributes to sum, with the others, to rock formation permeability.

In system types nested in sedimentary rock formation, such as petroleum and water exploitation, the application of identified intervals open to reservoir are very useful. So, in petroleum systems, are used for defining depths where would be shooted the pipes for the well exploitation. Regarding water wells, the thicknesses with reservoir communication are used for collocating gravel packing, helping the exploitation efficiency. In geothermal systems, intervals which have communication with reservoir could be useful for identifying heat feed and if there is some of permeability, its correlation for the water entrance, for the exploitation backup.

In volcanic systems, communicated intervals with reservoir, are related with small fissures of altered rock by tectonic tension strengths of adjacent structures or also by hydrothermal alteration. Understanding the nature and distribution of communicated intervals with reservoir is particularly relevant for well targeting and useful in providing conditions and constraints to reservoir models (Glynn-Morris et al., 2011). In this work, particular analysis techniques are used for identifying intervals with communication to reservoir, taking into account geological structures, lithological distribution of rock formation with their respective properties correlated with thermodynamic properties.

2. CONCEPTUAL FRAME

Identification of intervals communicated with reservoir, can be carry out by applying different techniques. In geothermal systems initially can be located during a completion test with pressure temperature measurements, and if it is possible include spinner (Kamah et al., 2005). Uses of obtained data results from spinner in the Kamojang field are described by Sudarman et al., (2000). Pressure, temperature and spinner (PTS) data, ordinarily constituted the primary source data used for interpretation of feed zones. More recently, the interpretation and understanding of feed zones has been enriched by combining PTS data with acoustic formation imaging logs and continuous core (Glynn-Morris et al., 2011).

Using temperature and pressure gradients of some wells of Cerro Prieto Geothermal field, Castañeda (1981) identified existence of intervals with communication to reservoir, which classified as feed zones. Several studies such as Glynn-Morris et al. (2010) and Ramsay et al. (2011) among others have been carried out for correlating properties of rock formation from core samples, with the intervals communicated with reservoir. Correlations between identified fractures and feed zones at Wairakei-Tauhara geothermal field have been documented at depths greater than 2000 m (McLean et al., 2011). The importance of involving different techniques in an integrated approach highlights the obtained results. A study of interpretation of feed zones to map subsurface permeability, in domes of Olkaria geothermal field, was carried out by Mbithi (2016).

The basic operation of geothermal energy source involve water entrance and heat source, so, the fluids in the reservoir are heated and are provided by energy until obtaining thermodynamic conditions at saturation state. The acquired energy of fluids is transported from the bottom hole to the surface using the water as transport vehicle of heat being applied for electricity generation. This general methodology has been used ordinarily in geothermal fields and it is the conventional exploitation technique.

The hydrothermal reservoirs involve conditions for an efficient for geothermal exploitation; however for achieving an efficient and continuous operation it is required the support given by recharge water entrance. The main characteristic of this process is to take care in equilibrium between the produced mass and water recharge. Because under unbalance between the extracted mass by the exploitation and a small mass of water entrance, the fluid in reservoir increases its temperature changing steeply, its saturation state (i.e increases the steam-water ratio). For cases in which exploitation is greater than recharge entrance, systems in liquid phase show evolution to two phases (liquid and steam) and until could change toward only one phase (steam).

3. ANALYSIS CASE IN A MEXICAN GEOTHERMAL FIELD

This work is focused to analyze and understand the behavior of one of the geothermal fields in México, Los Humeros, located at country central east portion, which shows particularities in geochemical and thermodynamical wells performance. In México, there is a high interest in developing clean energies and the advantage over fossils is that geothermal resources besides, be clean are renewable and even more, are continuous, not intermittent. At present 66.5% of the installed capacity in the country comes from fossil fuels, mainly natural gas and coal, with hydroelectric plants representing 18%, wind power plants 6.8%, solar (photovoltaic) 2.6%, nuclear 2.3%, and geothermal-electric plants 1.3% (Gutiérrez-Negrín et al., 2020). It is worth mention that 59.2% of the total power capacity in México is owned and operated by the state enterprise CFE (Comisión Federal de Electricidad), including almost all (97%) the installed geothermoelectric capacity. The remaining power plants in operation are owned and operated by private companies. There are currently five fields in production, Cerro Prieto, Los Azufres, Los Humeros, Las Tres Vírgenes and Domo San Pedro with an installed capacity of 1005.8 MWe and a running or operating net capacity of 947.8 MWe.

The Los Humeros geothermal field (LHGF) is located about 280 km east of Mexico City, within the Los Humeros volcanic caldera, at an elevation of more than 2,500 m above sea level. The Los Humeros caldera, measuring about 25 km in diameter, lies near the Eastern end of the calc-alkaline Trans-Mexican Volcanic Belt that is associated with the subduction of the Cocos plate along the Middle American Trench (Ferrari et al., 2012). Nested within the main caldera are smaller sub-calderas or collapse structures. The currently developed geothermal field lies entirely within one of these smaller calderas, known as the Los Potreros Collapse structure. A map of LHGF location is shown in Figure 1.

The objective of this study is to understanding the wells behavior related with thermodynamics and petrophysical characteristics, taking into account the geological structures neighboring. Were selected wells of the north zone of the LHGF located along eastern to western, separated by different geological structures, which are shown in Figure 2.

The selected Wells array for applying the methodology analysis in the north zone of LHGF was designed according to geological structures existing in this area. So, in this work Sector 1 (S1) is the zone bounded by “La Antigua” and “La Cuesta” faults. While the Sector 2 (S2) is between "La Cuesta" and "Los Pájaros" faults and Sector 3 (S3) is between “Los Pájaros” and “Las Víboras” faults. For this study, in Sector 1, the wells H9 and H7 were analyzed, in Sector 2, the wells H30 and H33 and in Sector 3, the wells H17, H32, H55 and H64.

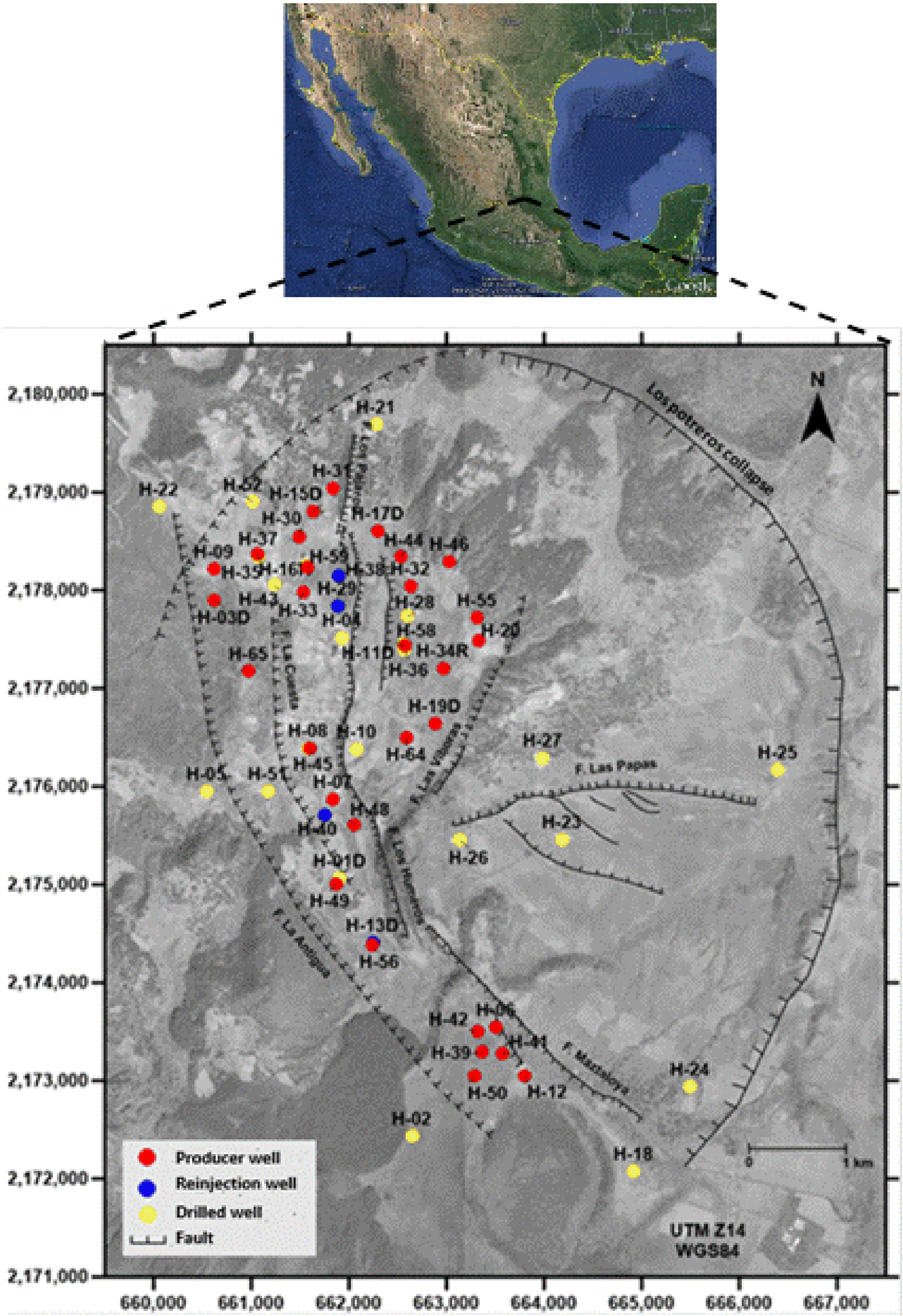

Figure 1: Location map of Los Humeros geothermal field with drilled wells and main geological structures.

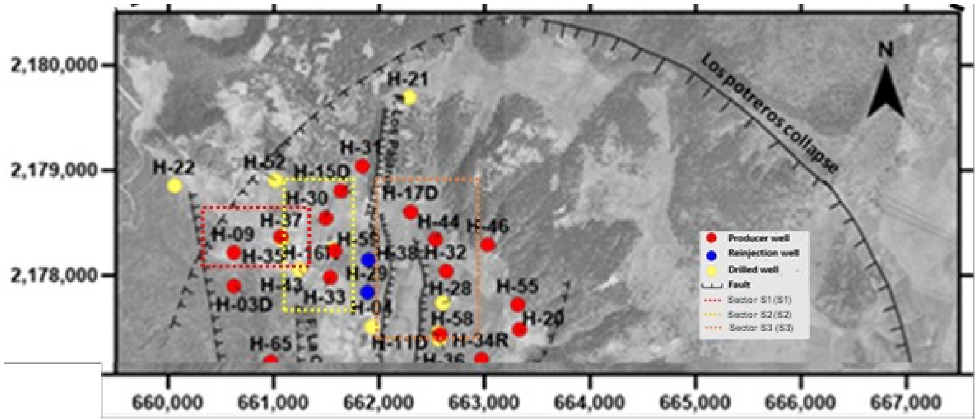

Figure 2: Description of the fractionated sections, for the analysis in this work, of the north zone of Los Humeros geothermal field.

The methodology analysis involves useful information generated during well drilling, such as fluid circulation losses, penetration velocity, lithology in conjunction with thermodynamical (pressure-temperature) logging (Arellano et al., 2015). Fluid circulation losses zones of drilling data provide an indirect gross measurement of the open-hole wellbore permeability. During the well completion stage, pressure and temperature profiles measurements are used, whose results help to verify intervals were cooldown by drilling fluids, their thermal recovery capacity and for identifying the depth of the major feed zone. The intervals with cooldown but with thermal recovery capacity are associated with the thermal reservoir and under this concept, in this study, was applied the analysis methodology.

Preferably are used pressure and temperature measurements with repose times in the rank of 24 hours and more time if it is possible, but avoiding to achieve heating stage, only the necessary time within the pseudo steady state. Using profiles at such conditions it was feasible to distinguish abnormal changes in temperature associated with intervals of thermal regression in some cases and others with heating intervals. Results of these measurements are useful for defining the depth locations of slotted and smooth liners. Some of the ways feed zones can be identified are by fluid loss or gain and by the temperature changes in the wellbore.

Using data of wells, located in studied zones it was constructed a graph correlating the profile of fluid losses during drilling, with found lithology from recovered cutting samples and pressure and temperature measurements at two different repose times. Analysis through graphs of selected wells located in Sector 1 are shown in Figures 3 (well H9) and 4 (well H37).

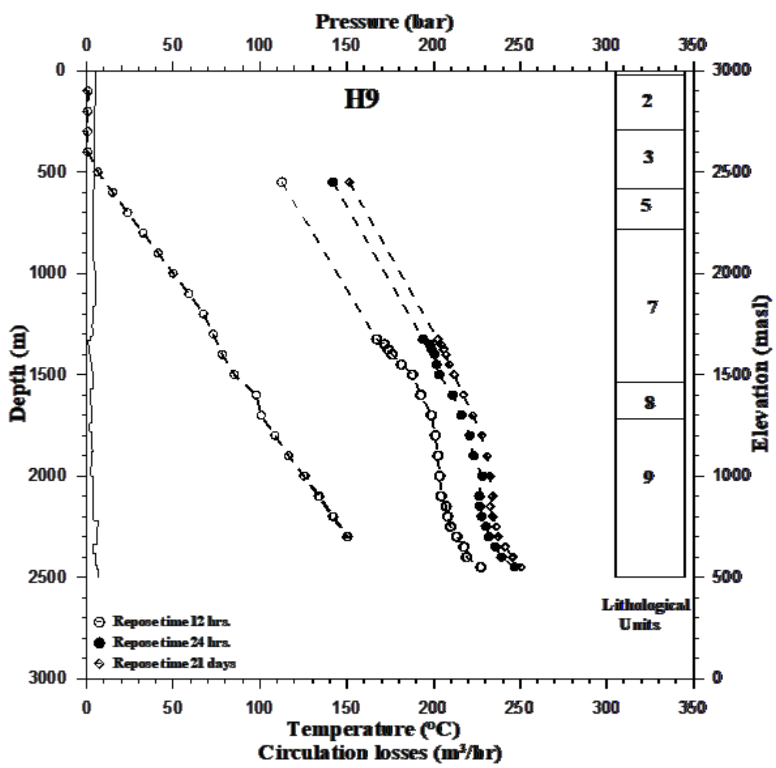

Figure 3: Temperature measurement profiles taken at 12 hours, 24 hours, and 21 days of repose time; pressure profile at 24 hours of repose time, correlated with lithology and fluid circulation losses during drilling of well H9.

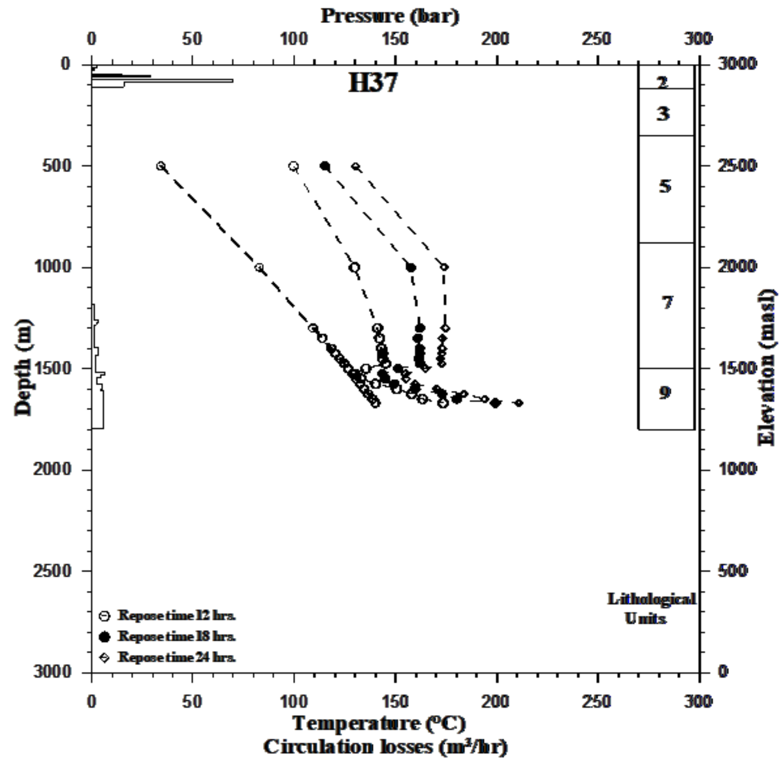

Figure 4: Temperature measurement profiles taken at 12, 18, and 24 hours of repose time; pressure profile at 24 hours of repose time, correlated with lithology and fluid circulation losses during drilling of well 37.

The graphs of Figures 5 and 6 show analyzed parameters behavior of wells (H30 and H33) which are located in Sector 2 bounded by La Cuesta" and "Los Pájaros" faults, such as described in Figure 2.

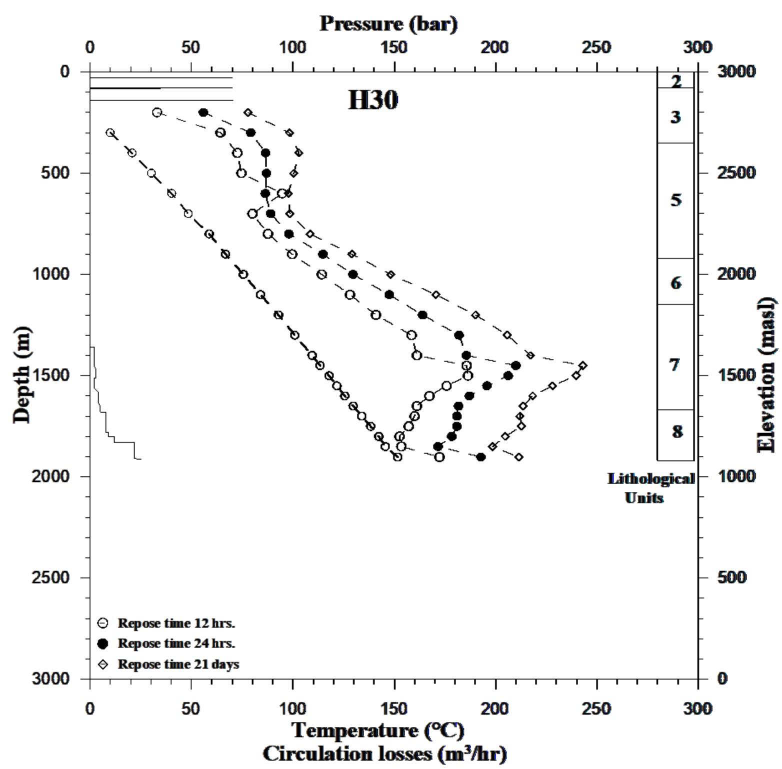

Figure 5: Temperature measurement profiles taken at 12 hours, 24 hours, and 21 days of repose time; pressure profile at 12 hours of repose time, correlated with lithology and fluid circulation losses during drilling of well 30.

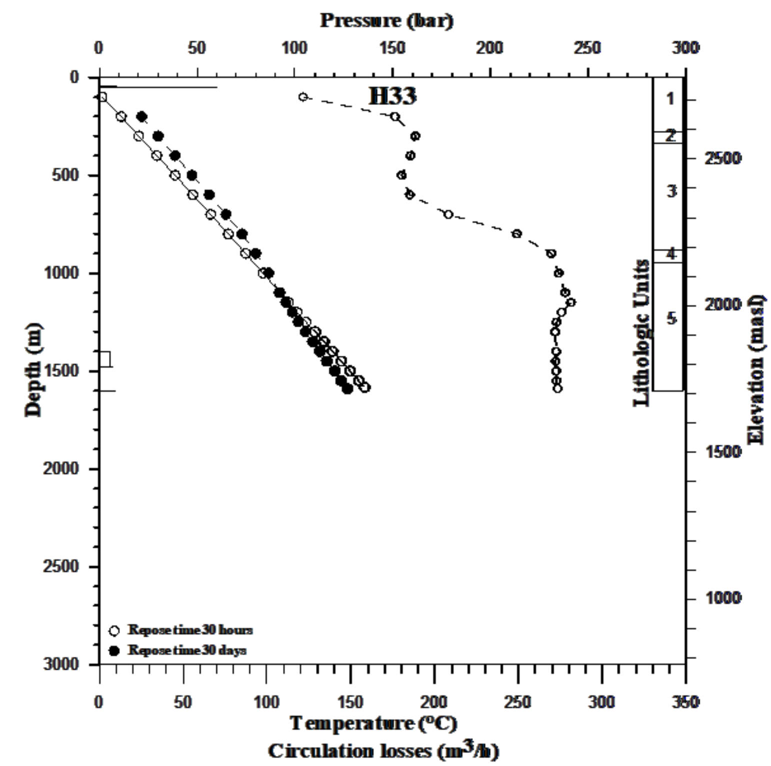

Figure 6: Temperature measurement profiles taken at 30 hours of repose time; pressure profile at 30 hours, and 30 days of repose time, correlated with lithology and fluid circulation losses during drilling of well 33.

Graphs used in the methodology analysis of wells H17, H32, H55 and H64, located in Sector 3 (S3) between "Los Pájaros" and "Las Víboras" faults, which are shown in Figures 7 to 10.

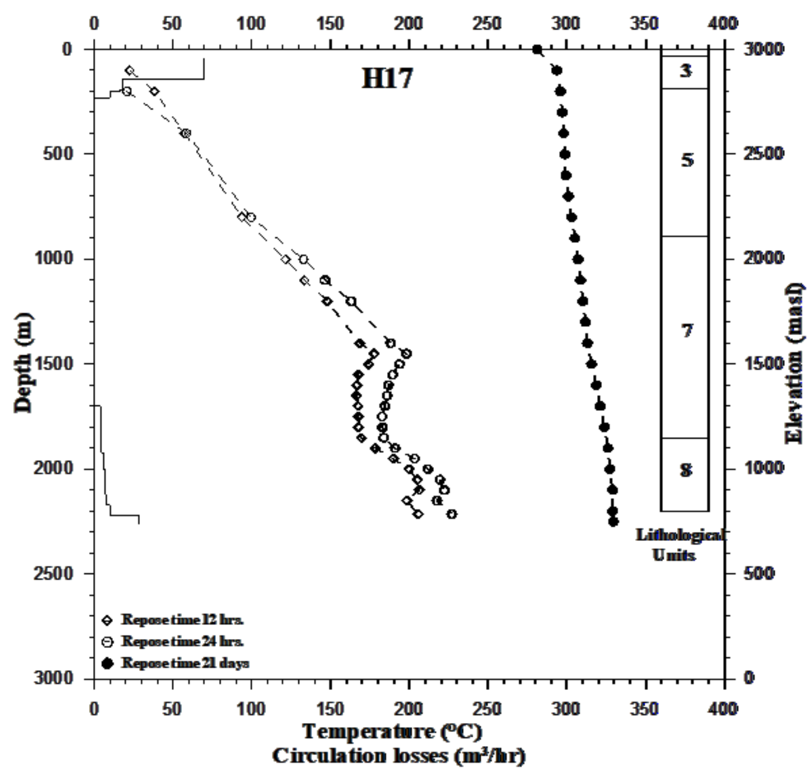

Figure 7: Temperature measurement profiles taken at 12, 24 hours and 21 days of repose time; correlated with lithology and fluid circulation losses during drilling of well 17.

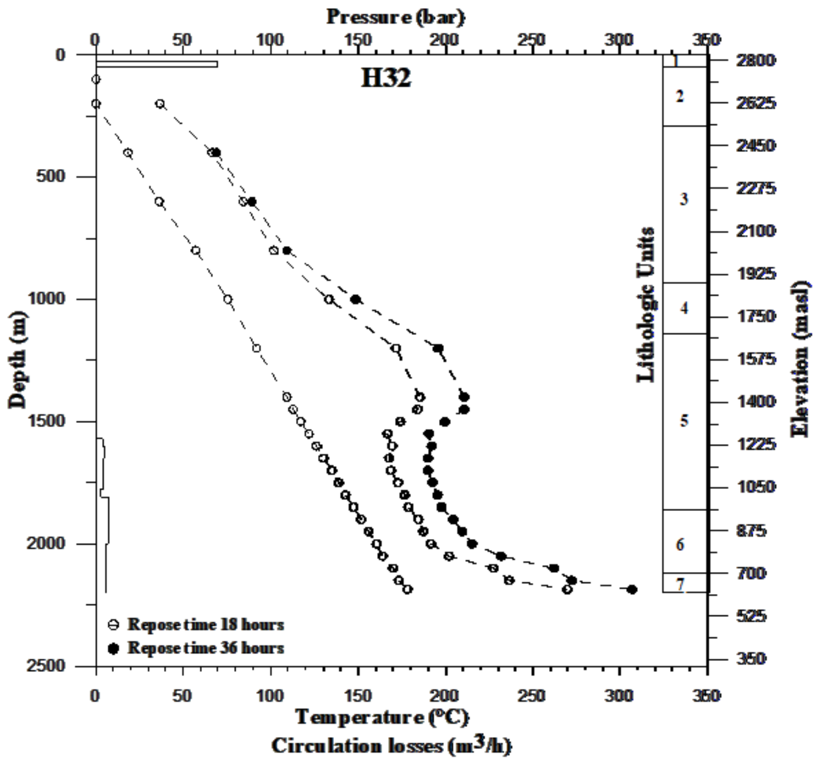

Figure 8: Temperature measurement profiles taken at 18 and 36 hours of repose time; pressure profile at 36 hours, correlated with lithology and fluid circulation losses during drilling of well 32.

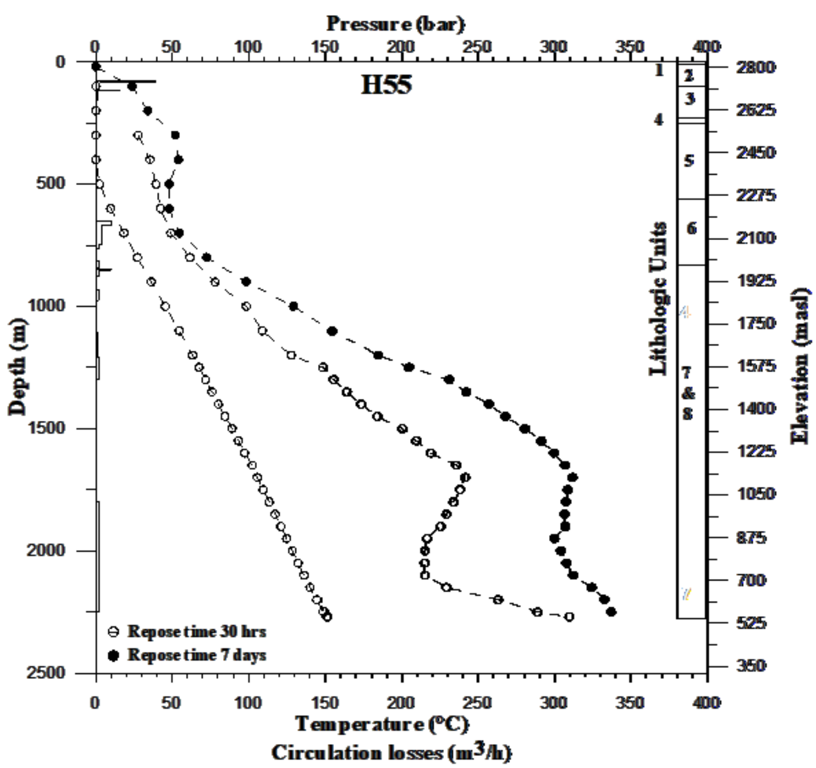

Figure 9: Temperature measurement profiles taken at 30 hours and 7 days of repose time; pressure profile at 30 hours, correlated with lithology and fluid circulation losses during drilling of well 55.

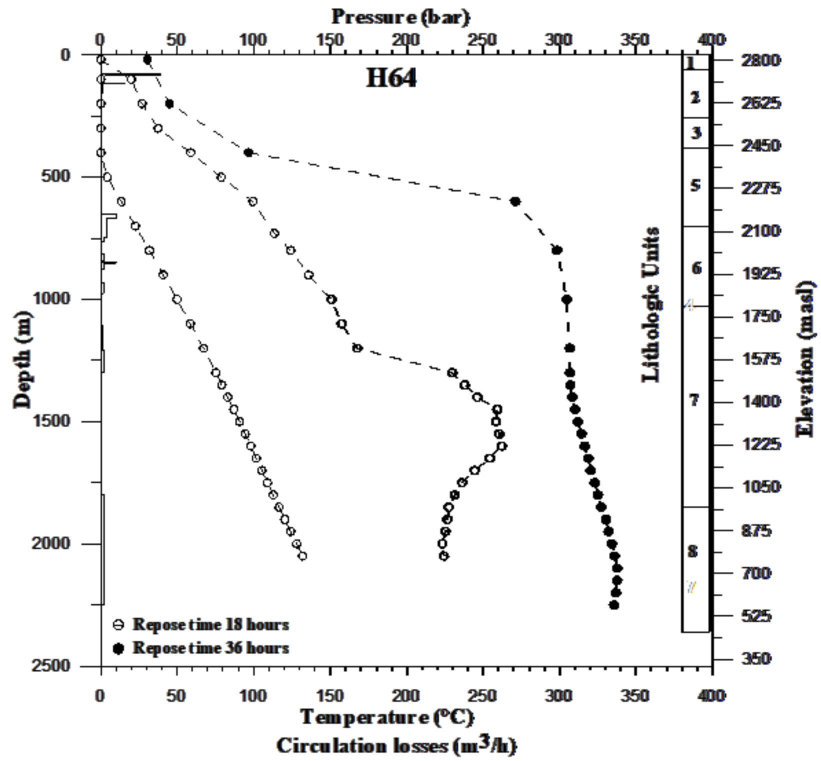

Figure 10: Temperature measurement profiles taken at 18 and 36 hours of repose time; pressure profile at 18 hours, correlated with lithology and fluid circulation losses during drilling of well 64.

4. RESULTS DISCUSSION

From Figure 3, it can be seen that well H9 shows a conductive profile with a temperature increase constant until about 1900 m depth; however, there is a small thickness between 2100 and 2200 with a slight temperature decrease of 2 °C. In general, the well behavior is with constantly ascendant temperature. This well does not show the marked temperature decrease appearing in wells of the eastern section of the North zone.

The well H37 is located just at the border with the "La Cuesta" fault, it can be seen, from Figure 4, a constant increase temperature except for a slight decrease in a short thickness between 1550 and 1600 m depth.

As can be seen in Figure 5, the well H30 shows a constant temperature increase until 1500 m depth (which is correlated with the heating zone). However between 1500 and 1850 m depth, show temperature decrease and after, a new temperature increase from 1850 to 1900 m depth, in correlation with about 20 m^3/h of circulation losses.

With respect to the behavior of the well H33, shown in Figure 6, it can be identified, through the temperature profile that heating in the well occurs until about 1300 m depth. The constant temperature profile, after the maximum achieved, indicates convection into the well, along the lithological unit 5.

With exception of well H17, the three analyzed wells show an ordered sequential and continue of lithological Units, even though, Lithological Units 1 and 4 of well 55 are too short in length. Besides, in this well there was uncertainty for identifying the end of Lithological Unit 7 and start of Unit 8. Also it is highlighted that during drilling did not were found some evidences related with Lithological Units 2, 4, and 6 in well H17.

Temperature measurements of all these wells located in sector 3 show a marked constant increase, associated with heating until about 1500 m depth. This temperature increase occurs in lithological Unit 7, excepting well H32, which occurs in lithological Unit 5. After this heating point, all the wells show a temperature decrease; in well H17 by an interval of about 300 m length, H32 with 200 m length, and H55 and H64 with 400 m length.

In this work, each rock formation block is called, from west to east, as sectors 1, 2, or 3. The characteristic behavior of each sector is as follows: Wells located in Sector 1 show, through temperature profiles a constant increase just until depths of about 1500 m with a short thermal decrease and its immediate temperature increase. Wells located in Sector 2 show temperature increases until about 1400 m depth, followed by temperature decrease. Meanwhile, wells located in Sector 3 show temperature increase until depths higher than 1500 m, followed by a long interval of about 400 m of temperature decrease, but with an interval of thermal recovery deeper. Along the length of space where analyzed wells are located, it can be identified different geological structures forming compartments for each block influenced by the geological structures.

5. CONCLUSIONS

From the obtained results, it can be see that geological structures influence in behavior temperatures distribution in wells drilled in the volcanic formation such as in LHGF.

A highlight thermal behavior is that really the geological structures form rock formation blocks, so, each well group in each block bounded by the faults has a single and characteristic temperature profile.

It was found that different geological structures can establish compartments for each block identified by thermodynamic particular characteristics.

Compartmented behavior of the LHGF, can be identified by distribution of pressure and temperature profiles also lithology and circulation losses.

Application in different wells, of shown methodology, allows identifying the continuity of strata through the same field sector which is useful for the development of completion designs in new drilling for this sector.

The correlated parameters through this methodology allow determining firstly the intervals which have only heating and distinguish them, from those that are related with geothermal exploitation feed.

The appropriate knowledge of each communicated interval with the reservoir with its respective level depth is useful for defining firstly, the original reserve of resource and according the well results, to select its appropriate utilization, so, as production or as reinjection.

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