Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geochemical and Thermohydraulic Characterization of Some Production Wells of New Geothermal Project Las Pailas II in Costa Rica

Jessica Arias Hernández, Yosniel Garrido López,

ICE, UEN PySA, CSRG, Apartado postal 10032-1000, San José, Costa Rica

jarias@ice.go.cr ; ygarrido@ice.go.cr

Keywords: Exploitation, Chemical Characterization of wells, Case Histories, Las Pailas II Geothermal Field, Costa Rica.

ABSTRACT
Las Pailas II Geothermal Field is a new Project in Costa Rica that is their final stage of development and is scheduled to enter into operation by mid-2019, it is located in the foothills of the southern sector of the Rincon de la Vieja Volcano, and is next to Pailas I Geothermal Field. Due the limitations to get the resource within the national park where the related volcano is located, its operational design was proposed through the use of directional drilled wells that allow access to the resource in an underground way, and also to preserve the environment and decrease the constructive impact were designed works taking full advantage of the building space. The reservoir is exploited by 21 drilled wells, of which 12 are producers and 9 reinjectors. During 2018 the first productive evaluations of the wells were carried out. In this work data of different wells of the PL-11, PL-12 y PL-13 platform are presented, where the geochemical and thermohydraulic characteristics of the area are presented.

1. INTRODUCTION

Costa Rica is located in the southern part of the Central American isthmus, between Nicaragua and Panama. The country extends over an area of approximately 51,000 km^2 and has a population greater than 5 million. The actual development of geothermal energy in the country is located in the Guanacaste Volcanic Range, where there are two geothermal fields in operation: the Alfredo Mainieri Geothermal Field (AMGF, formerly Miravalles) located on the southern flank of the Miravalles Volcano which currently has an installed capacity of 163 MW and has been producing continuously for 25 years successfully, and the Pailas Geothermal Field which is located in the foothills of the Rincon de la Vieja Volcano.

The country aims to be "carbon neutral" by 2021, the task of reducing net national CO_2 emissions to zero. This initiative was launched in 2007, where the government administration establishes the commitment to focus efforts to achieve that goal. The conservation of the environment and the reduction of dependence on the importation of fossil fuels are important issues in the country's energy policy; inthe "National Development Plan 2014-2011" the objective was set to achieve that 95% of the electricity generation in 2014 is will be with renewable sources, MIDEPLAN (2010); and since 2015 the energy matrix reaches 98 - 99% in clean energy generation, see figure 1.

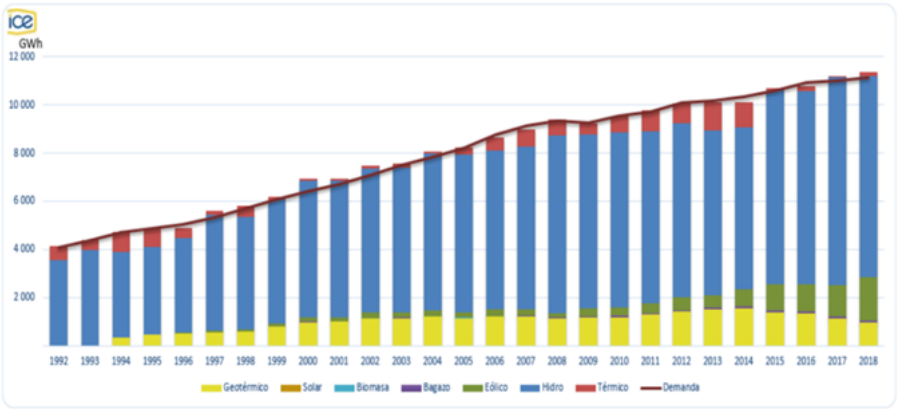

Figure 1: Gross Energy production by source vs demand (1992-2018), CENCE (2018).

This is how in the following years the new projects are concentrated in the surroundings of the Rincon de la Vieja Volcano, developing the Las Pailas I project located to south of the volcano, which was commissioned in 2011 adding 35 net MW to the system with a Binary plant (41 MW gross). During the evaluation studies of the geothermal resource for that unit, two additional geothermal prospects were identified adjacent to the Las Pailas field and of enough potential to double the generation capacity in the field and, in addition, to install a similar generation capacity in a geothermal prospect contiguous named Borinquen, ICE (2015).

In 2019, the Las Pailas II unit enters production with a condensation plant capable of generating an additional 55 MW, being the most modern in Central America and the Caribbean, ICE (2019). This field is located next to Las Pailas I to the right side, close to the town of Curubandé, see figure 2. Towards the west sector, the Borinquen Geothermal Project (BGP) is under development, which is expected to enter production by 2026 providing other 55 MW in its initial stage.

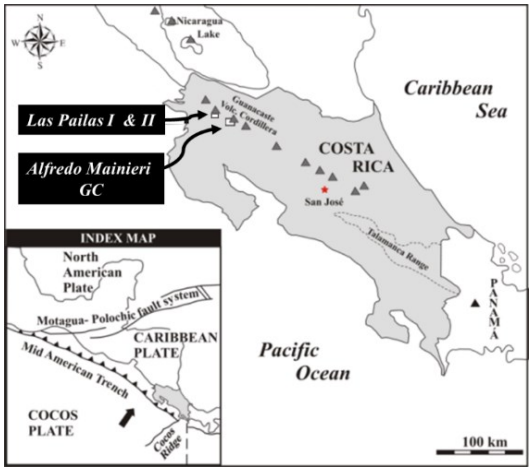

Figure 2: Location map of Alfredo Mainieri and Las Pailas Geothermal Fields (modified from Vega et al. (2005)).

1.1 Background of Las Pailas II

In cooperation with the Government of Japan, in 2013 West JEC and ICE concluded the execution of a preparatory study to estimate the additional resources of the new Las Pailas II Field, which allowed to negotiate financing through the ODA Loan (Official Development Assistance). Financing for the construction work of the Las Pailas II project remains under the attention of the Japanese Agency for International Cooperation (JICA). ICE has accumulated abundant experience in geothermal energy projects since the realization of the Miravalles-I project (1986-1994) and has decided to take over the execution of a new unit in Las Pailas, through its own technical resources or through the tender to subcontractors through acquisition packages, for the construction of the power plant and its main equipment, ICE (2015).

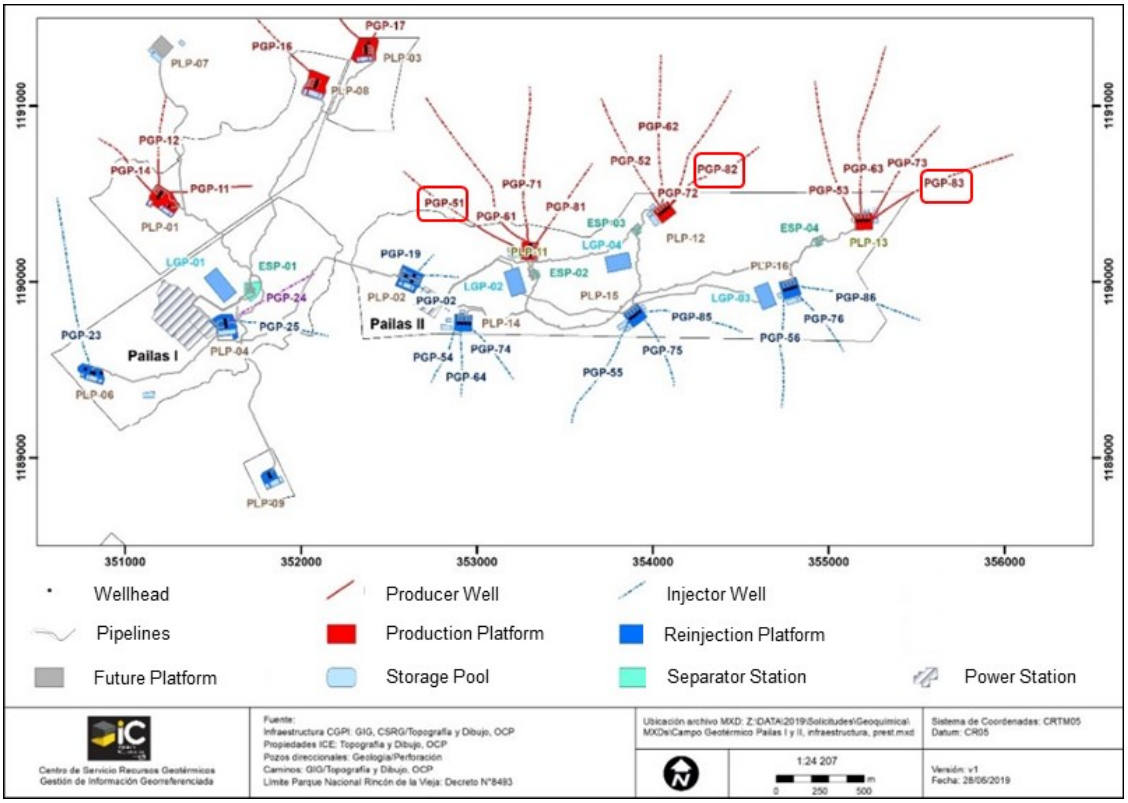

Figure 3: Conceptual Map of Las Pailas I and II Geothermal Fields.

Exploration studies in the area began in 2001 with the initial development of Pailas I, and the first exploratory well in the area of Pailas II was drilled in 2002 corresponding to PGP-02 and by 2012 the PGP-81. These wells combined with those already carried out in Pailas I served as inputs to perform a total evaluation of the geothermal potential in the Las Pailas field and whose result indicated the existence of enough resource capacity. Consequently, ICE established the delimited area of the project for the construction of a new power plant called Las Pailas II, West JEC (2013) with a total area of 217.4 ha, see figure 3.

The drilling process continued until the last well was completed in 2018; Table 1 shows the drilling progress from 2001 to 2018. The project has 3 platforms located in the northern sector, each platform has 4 directional producing wells that allow them to achieve greater extension of the reservoir, and in the southern part reinjection zone is located that has 3 other platforms with 3 wells each one.

The first well tests evaluations were completed in 2019, where a total contribution of between 404-963 Kg / s of total mass produced was determined depending on the well opening conditions. Having the power plant a total requirement of 121 kg / s of steam flow, there is an abundant resource to operate wells at medium capacity and ensure the sustainability of the resource, Castro & Torres (2019).

Table 1: Drilling well chronology in Pailas II

Year	Drill Wells in Pailas II
2001	PGP-02
2012	PGP-81
2014	PGP-64, PGP-71, PGP-72, PGP-75
2015	PGP-73, PGP-54, PGP-74, PGP-55, PGP-56, PGP-76
2016	PGP-53, PGP-52, PGP-85, PGP-86
2017	PGP-83, PGP-51, PGP-82, PGP-61, PGP-63
2018	PGP-62

All the wells developed are directional to cover different areas, avoiding interference between them from the same platform, which additionally brings the benefit of minimizing the environmental impact due to excavations or fillings to create additional platforms. The depths of the wells range from 1155 (1358) m to 2210 (2409) m in vertical depth (measured depth). Each well produces enough steam to generate between 4.0-13.9 MW with WHP between 6.30-24.60 bar at maximum flow and the injectors accept between 43-227 Kg / s each, data obtained for their first evaluations in the initial conditions of the field.

1.2 Positive impacts in the area

The construction of the Project allowed the generation of new sources of employment in the area. On the other hand, with the development of the Project an aqueduct was built to bring drinking water to 3000 people from neighboring towns, ICE (2019). It is expected that with this actions the local economy and social services will be greatly improved. The impact on the existing flora and fauna is expected to be small thanks to the minimization of the land modifications in the area. The results of the prediction of the impact of hydrogen sulfide (H_2S) emissions, noise and water quality comply with environmental standards, Janzen, D. (2017). In addition, the ICE rescued more than 700 animals in the geothermal field and reintroduced them into protected areas during the development of the project and the wildlife monitoring cameras installed have confirmed the return of jaguars, peccaries and tapirs to the Curubandé area, ICE (2019). The design of the power house placed in an excavated terrain diminishes the landscape impact and the Project mixes its characteristics with those of the surrounding natural landscape. In addition, the estimated amount of greenhouse gas emission reduction as a result of the project is 20,067 tons of CO_2 per year, West JEC (2013).

This article aims to show the chemical and thermohydraulic characteristics of three representative wells of the Las Pailas II geothermal field. These wells are characterized by presenting a heterogeneity of their parameters.

2. GENERAL GEOLOGY OF THE PROJECT AREA

In the area there is a lithostratigraphic homogeneity in the northern part of Pailas II, and it has a good correlation with the outcropping units. This includes diverse volcanic and volcaniclastic material deposited in explosive and effusive phases, as well as during periods of volcanic quiescence, Chavarría *et al.* (2010). During the drilling stage five stratigraphic units were recognized, from the oldest to the most recent: Aguacate Group, Bagaces Group, Liberia Formation, Pital Formation, Recent Products of the Rincon de la Vieja volcano. They have a great continuity in terms of roof elevation and thicknesses, these units are briefly described below in ICE (2017) a and Chavarría et al. (2010), see figure 4.

-Aguacate Group (AG): This unit includes andesitic lava sequence intercalated with pyroclastic rocks, sedimentary rocks, reworked material, andesitic dykes and hypabissal rocks. The thickness of the Aguacate Group varies from 250 to 790 m (without having reached the base). These lavas are characterized by their secondary permeability along fractures, and now are intensely altered.

- Bagaces Group (BG): This unit corresponds to a pyroclastic flow and tuff sequence (ash, lithic, pumiceous and crystal lithic tuffs) with alternating lavas, reduced thicknesses of dacitic lava and ignimbrites, lake deposits and scattered dykes. Is considered that these lavas mark Cañas Dulces caldera border. The thickness of this unit varies from 360 m to 710 m. Permeability in the upper part of the Bagaces Group is associated with lithologic contacts while permeability in the basal section is associated with fractures in lavas and highly consolidated tuffs.

- Liberia Formation (LF): This formation has been drilled in the deep wells and has been correlated with an extensive pyroclastic rock sequence cropping out at the surface. This rhyolitic tuff is formed by various explosive events that contain lithic, pumiceous, crystal lithic pyroclasts and characteristic biotite and primary quartz crystals. The thickness goes from 3 m to 231 m. We have observed that within the caldera the thickness of this unit thins out towards wells, and thicker towards the north and northwest.

- Pital Formation (PF): This formation consists mainly of pumiceous pyroclastic events and few lacustrine deposits. It has been found in all of the deep wells with thicknesses varying from 170 m to 347 m. It is dacitic to rhyolitic in composition and was formed from pyroclastic events with high white pumice content. Primary minerals that may be found in these flows are green or brown hornblende, and reworked biotite locally.

- Rincón de la Vieja volcano Recent Products (RVRP): This unit consists of a sequence of debris avalanches and lavas from the Rincon de la Vieja volcanic complex. Within the caldera the thickness of this unit varies due to paleotopography and proximity to

the source vent. The thickness varies around 140 m, which have been interpreted as forming part of the inner limit of the caldera border.

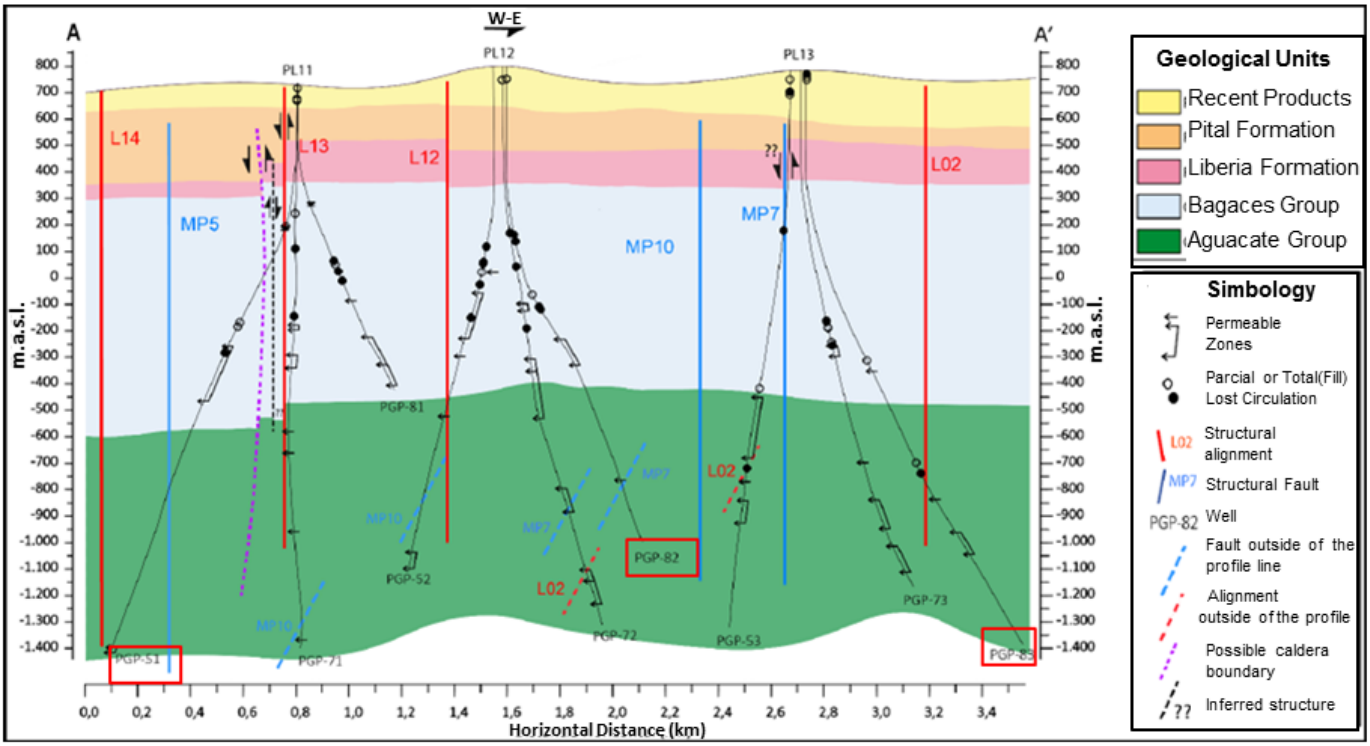

Figure 4: Cross Section West-East of Las Pailas II Geothermal Fields, modified from ICE (2017)a.

It is believed that towards the southern sector in the vicinity of the PL-14 the edge of the Caldera San Vicente is located. That is evidenced in the roofs of the LF, BG and AG Units, in the PL-14, they are observed lowered with respect to the Units in the wells of PL-11 and PL-12 platforms according to the illite pattern, indicating a possible decrease in the temperature gradient in that sector, ICE (2017) a. The San Vicente Caldera is associated with the Pailas I reservoir, while Las Pailas II is geographically out of this Caldera; however, due to the direction the wells of PL-11, PGP-51 and PGP-61 where drilled (northwest), they enter this area.

2.1 Geothermal Conceptual Model

The geothermal system in the Las Pailas sector is considered to be a hydrothermal convective system. The meteoric water infiltrates the depths where it is heated by the host rock associated with the magmatic chimney of the Rincon de la Vieja volcano. It has been recognized that different geological formations are contributing to store geothermal fluids (Aguacate and Bagaces Group mainly), and it is believed that faults and their associated fractures are the main routes for fluid movement, allowing underground fluids to migrate with high temperatures, which are driven by hydraulic and conductive forces, ICE (2013).

3. PRELIMINARY GEOCHEMICAL CHARACTERIZATION OF SOME WELLS OF THE RESERVOIR IN UNIT 2 OF THE PAILAS GEOTHERMAL FIELD

This field like Pailas I both share a reservoir of liquid dominance with sodium-chlorinated fluids composition of neutral pH in general, multiaquifer which some wells have a tendency to calcium carbonate scaling and others in dependence of the well opening manifest acid characteristics. The temperature of the water-dominated geothermal reservoir was about 230-260 °C at the beginning of the exploitation with conductivities above 21000 µS/cm. According to the first productive evaluations of the wells completed during 2019, a significant gas content between 0.07 and < 1.5% gas p / p bar a. was found, this condition was observed during the drilling process of some wells, where high wellhead pressures were shown that showed the presence of these gas zones. This characteristic is absent in Las Pailas I whose field has a very low gas content (< 0.4% gas w / w bar a.).

Chloride vs. Enthalpy models allow to identify relationships between different processes and fluids in a geothermal system, because they use the heat content combined with the indications of dilution or concentration processes in order to determine phenomena such as: conductive cooling, boiling and mix, IGME (1985), however these phenomena can be evaluated in the long term as soon as the field is operational. A chloride-enthalpy diagram was performed to examine the fluids of the producing wells of Pailas II (PL-11, PL-12 and PL-13 platforms) representing the chemical information of the basal state, because the operation of the field had not started at the moment. The data were obtained from the first productive tests, see Figure 5; Additionally, it included: 2 producing wells of Pailas I (PGP-03 and PGP-17), a point representing the reinjection fluids of Pailas I and the temperature of the reservoir fluids is indicated taking as the reference point (RP) the PGP-72 with 259 ° C.

The data obtained from the sampling of discharge water from wells in the maximum flow condition (MF) was used to make the graph, and the chloride content was calculated at reservoir conditions from the discharge fluids. Because there is direct measurement data in the deep wells, the dynamic enthalpy calculated from the dynamic temperature was plotted, which was determined directly from the fluids in the reservoir and then converted to enthalpy using Keenan steam tables et al., (1969), the results of this enthalpy are very similar to those obtained by enthalpy calculation from quartz geothermometers. During the realization of the dynamic profile in the wells PGP-53, PGP-63, PGP-83, and PGP-62 the dynamic temperature could not be obtained, so to obtain the enthalpy in those wells the calculation was performed using the Na-K-Ca geothermometer, because it fits better at reservoir temperatures above 230 ° C, Fournier, (1979).

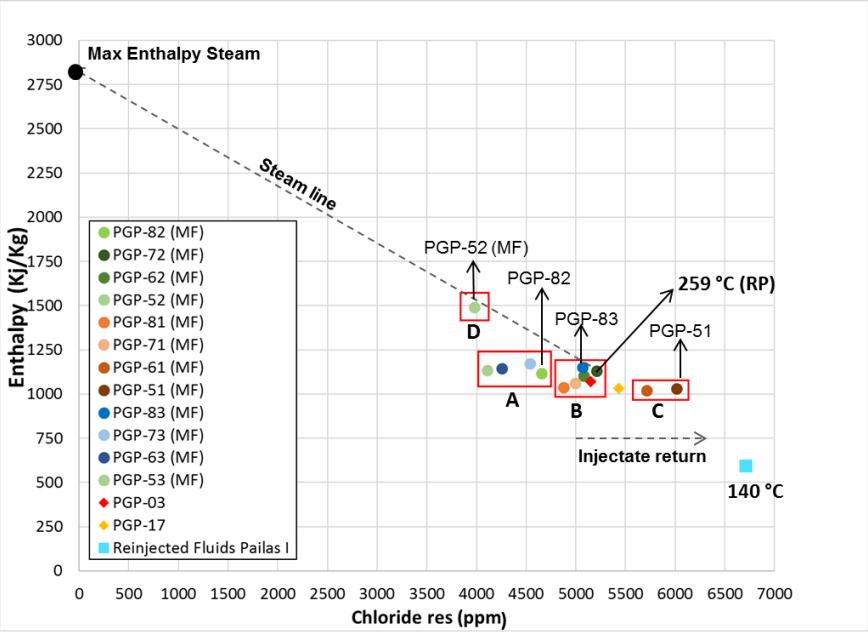

Figure 5: Chloride-enthalpy diagram representing the initial composition of fluids of producers wells in Pailas II.

According to the results obtained in figure 5, it is possible to classify the wells broadly in 4 groups, identified in the diagram as A, B, C and D. For the purposes of this article, a well was selected from each group: A (PGP-82), B (PGP-83) and C (PGP-51), which in turn are located in different areas of the field and have lightly different geochemical-thermohydraulic-productive parameters. D corresponds to the PGP-52 which is a well with particular characteristics: in its condition of minimum flow the well produces mostly steam being the fraction of liquid mass reduced from 51 to 2 Kg /s, so it presents a higher enthalpy than the rest of wells (1447 kJ / kg), it is being located on the steam line to the left of the other wells; however, the additional characterization of this well is not contemplated.

Figure 6 shows a Schoeller diagram with the characteristics of the majority chemical species of the liquid phase for the three selected wells in the field. The wells have a very similar level in general; however, the differences occur in certain chemical species such as sulfate in PGP-83, bicarbonate in PGP-82, the content of chlorides in PGP-51 that mark the differences determined for these measured wells in sectors other than the field, the plotted data correspond to the discharge waters, also includes other wells from Las Pailas I (PGP-03), AMGF (PGM-21) and BGP (PGB-29); all the different fields shows similar chemical patterns but the AMGF has in general the lightest salinity and the fluids of the Las Pailas I - II and BGP are very related.

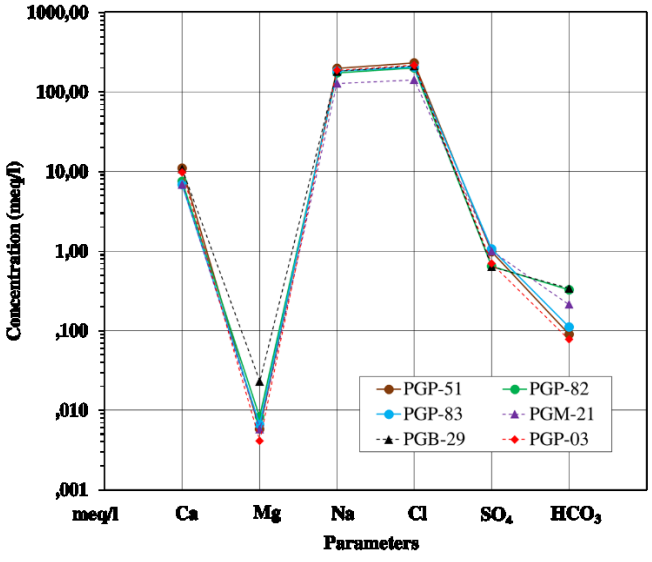

Figure 6: Schoeller Diagram representing the chemistry of fluids of some wells in Pailas II (PGP-51, PGP-82, PGP-83).

3.1 Well PGP-82

It is located on the PL-12 (Figure 3), has an orientation to the northeast from its platform in the central-north part of the field and has a measured depth of 1943 m (1794 m in vertical depth (VD)), reaching a 616 m horizontal displacement from the counter-well and with an average inclination angle of 27 °, ICE (2017) b. The first chemical data of the well were obtained after the evaluation carried out in May-2018: conductivities that reach 21000 µS / cm and concentrations of chloride and sodium close to 7150 ppm and 4000 ppm, respectively. The pH is neutral and the sulfate content is lower (~ 30 ppm) compared to the other wells and total silica (~ 700 ppm). The Na-K-Ca geothermometer indicates temperatures close to 260 ° C; this geothermometer is more reliable for high temperature ranges. The bicarbonate is moderate (<20 ppm) and Ca is maintained around 150 ppm. Studies carried out in the field by Castro & Torres (2019) identify calcite saturation in fluids but with a low tendency to embed it in the casing; however, due to these characteristics, the common and successful inhibition system used in Miravalles producer wells for more than 20 years will be used for production in this well.

The non-condensable gas (NCG) content is moderate and varies between 0.50 and 0.65% gas w / w depending on the opening percentage of the well; however, it is possible that this decreases when entering production, according to previous experiences observed in Miravalles and Pailas I. In general this well represents group A (Figure 5) and is characterized by presenting a lower salinity but with slightly higher enthalpy content and a moderate NCG content, than the other wells of the U2PGF.

3.2 Well PGP-83

It is located on PL-13 (Figure 3) and corresponds to the seventh producer-exploratory well that is drilled in the sector of Pailas II, has an orientation to the northeast from its platform at the northeast end of the field and has a measured depth of 2400 m (2168 m in vertical depth (VD)), reaching a horizontal displacement of 867 m from the wellhead (cellar) and with an inclination angle of 31.9 °, ICE (2017) b. The first chemical data of the well were obtained after evaluations carried out in June-2017 and April-2018, with conductivities reaching 21600 µS/cm and concentrations of chloride and sodium close to 7400 ppm and 4250 ppm, respectively. The chemical composition of the well is characterized by having a higher content than the other wells in sulfates (<68 ppm) and total silica (~ 790 ppm), the Na-K-Ca geothermometer indicates temperatures between 257-266 °C. The bicarbonate is low <10.0 ppm, the Ca remains around 130 ppm, so it does not require the implementation of an inhibition system for calcite inhibition, Castro & Torres (2019).

It has been seen that during the first hours of production the fluids manifested an acidic pH (4.5-6.0), however, as the reservoir fluids evolved it changes to a neutral pH. It is possible that the well captures some low-domain acid aquifer and it loses its influence when another dominant neutral aquifer starts circulating. In the mineralogy found during drilling it was observed by microscopic analysis anhydrite (Anh), pyrite (Py), Quartz (Qz) and sericite (Se), parageneses that are associated with an acid mineralogy, in ICE (2017) c it is argued that its presence could be due to immature geothermal fluids, which through fractures or failures reach the depths found in the core sample. The presence of acid mineralogy does not necessarily imply that at present the wells can produce acidic fluids, since it could be fossil mineralogy. Additionally, ICE (2017) c mentions the presence of a relatively shallow increase of anhydrite> 1% in the wells of the PL-13 in which the PGP-83 is located and in the PL-14, this mineral is associated with the presence of moderate to high temperatures and possible acidic fluids.

The non-condensable gas (NCG) content is significant, varies between 1.2 and 0.6 % p/p gas depending on the percentage of opening of the well; however, it is normal for recent wells to tend to decrease the NCG content once production starts in their operational life. In general, PGP-83 represents group B (Figure 5), it is characterized by having a higher salinity and slightly lower enthalpy content than group A wells, and an important NCG content. The enthalpy-Chloride diagram includes data from two wells of Pailas I, the PGP-03 and PGP-17 and it is observed that in the initial conditions of the fluids of the Pailas II reservoir these fluids resembles the chemistry shown by the wells of Pailas I, so the possibility of sharing fluids from the same reservoir (isolated by lithological and geomorphological barriers, but connected through important failures that promote fluid permeability between different areas of the reservoir), is not ruled out.

Fluids from both fields can be seen in the diagrams between boron(a) and sodium(b) vs chloride, see Figure 7. It shows more clearly the association of similarity with fluids of BGP and Pailas I, the figure also includes the Santa Maria thermal spring, which is an important point of discharge of the reservoir associated with U2PGF.

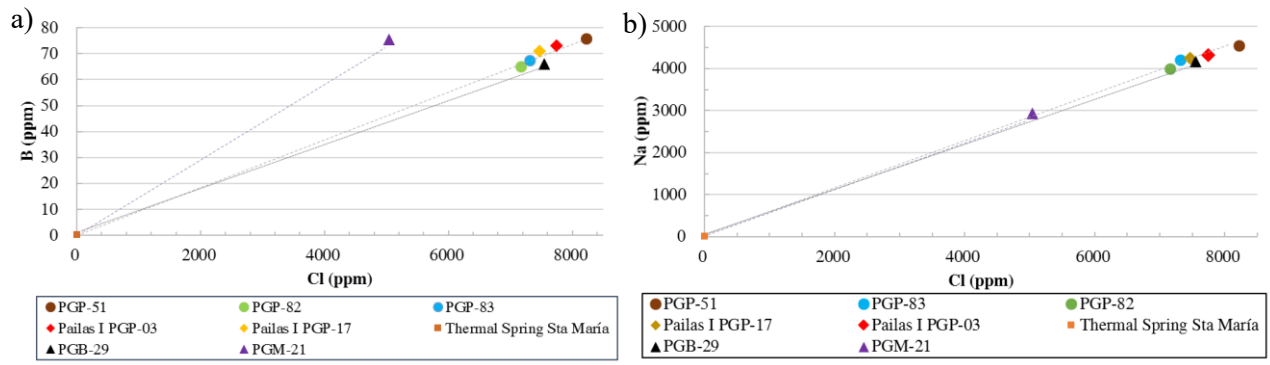

FIGURE 7: a) Chloride vs boron and b) Chloride vs sodium of the wells PGP-51, PGP-82, PGP-83 in Pailas II, also includes PGM-21(AMGF), PGB-29 (BGF) & Santa Maria Thermal Springs.

3.3 Well PGP-51

It is located on the PL-11, has a northwest orientation from its platform in the northwest part of Unit II of the Las Pailas Geothermal Field and has a measured depth of 2352 m (2151 m in vertical depth (PV)), reaching a horizontal displacement of 867.5 m from the counter arm and with an average inclination angle of 27.7 °, ICE (2017) d. The first chemical data of the well were obtained after the evaluation carried out in July-2018, it presents conductivities that reach 24000 µS / cm and concentrations of chloride and sodium close to 8200 ppm and 4500 ppm, respectively. The pH is neutral and the total silica (~ 600 ppm) is low compared to the other wells. The quartz geothermometer indicates temperatures between 237-242 ° C. The bicarbonate is low (<10 ppm) and Ca remains around 220 ppm, so like the PGP-83 it does not have a calcite saturation index important that requires implementing a carbonate inhibition system, Castro & Torres (2019).

The non-condensable gas (NGC) content is low <0.11% gas w / w. In general, this well represents group C, characterized by having a salinity higher than the rest of the U2PGF wells but with less enthalpy content and a low NGC content, characteristics similar to those of Pailas I, as mentioned in the geological section, the trajectory of this well makes it capture fluids inside the caldera of San Vicente. Additionally, Figure 5 included data on the reinjection fluids of the Unit I of the Pailas calculated for the reservoir conditions, which are introduced to the reservoir at 140 ° C, these present a higher salinity, it is possible that there is a phenomenon of mixing these with the fluids of PGP-51, see table 2. Castro & Torres (2019) indicates that this effect is mostly marked in PGP-51, the composition being similar to that of PGP-11 showed in 2014 and above to the PGP-16 in 2016, wells affected by reinjection of the PLP-02 of Las Pailas I. A comparison between chloride content in the reservoir and the Cl presented in the reinjected fluids is given in the table 2.

Table 2: Comparison of brine chlorides vs those calculated for the reservoir

Well	Date	Cl (0.94 bar a.) ppm	Cl (Reservoir) ppm
PGP-82	10/06/2018	7163	4656
PGP-83	19/05/2018	7316	5070
PGP-51	04/07/2018	8220	*6017*
Reinjected Fluids Pailas I	02/05/2018	*6709*	

4. COMPARISON OF PRELIMINARY THERMOHYDRAULIC PARAMETERS

Below is a description of the available thermohydraulic parameters determined for 3 wells of unit 2 of the geothermal field Pailas PGP-82, PGP-83 and PGP-51 as part of the tests to assess the initial conditions of the wells in the field, they are given in Table 3, the variables shown are in maximum flow condition, with the exception of the dynamic temperature of the well PGP-83 that was taken in MPD condition; the wellhead pressure at minimum flow (MPD) also is presented.

Table 3: Thermohydraulic Characteristics of representative wells of Las Pailas II Geothermal field.

Well	PGP-82	PGP-83	PGP-51
Date	28/05/2018	26/04/2018	24-06-18
Wellhead Pressure (bar a)	9,94	7,94	9,24
MPD (bar a)	18,54	14,24	12,44
Total Mass Rate (kg/s)	94	44	134
Enthalpy (kJ/kg)	1200	1202	1028
Steam Flow rate (kg/s)	24	11	23
Liquid Flow rate (kg/s)	70	33	111
Power (MWe)	10,8	5,2	10,6
Dynamic Temperature (°C)	256	240*	238
Condition	Biphasic	Biphasic	Saturated

4.1 Well PGP-82

The first evaluation was extended for 11 days, the PGP-82 shows high head pressures which increase significantly in the state of minimum flow when restricted with ranges ranging from 9.94 to 18.54 bar a., High pressures have been found in PL-12 wells. The enthalpy of the total fluid producing is 1200 kJ/kg. Prior to the start of the first productive evaluation of this well, the static temperature and pressure profile was performed. The static and dynamic profiles made during the evaluation, Figures 8A and 9A show that the static and dynamic temperature was very homogeneous between 256-258 ° C in the area below 1300 m deep, similar to that reported by the Na-K-Ca and Na/K(Fournier) geothermometer. Some residual effects are observed as a result of the fluids used during drilling, after 9 months of recovery, since it is observed that the most thermally affected areas correspond to the permeable areas defined in the well, Castro, S.(2018)a. In addition, the productivity index is good: <10 kg/s/bar, can produce a total mass of between 36-94 kg/s a comparison of the mass flow produced is presented in Figure 10, which shows a rate Very close steam flow with the PGP-51, see Figure 10B. With these parameters it is determined that: the productive characteristics of the PGP-82 are very good, and its incorporation into the production system of Pailas 2 would allow to provide approximately 24 kg / s of steam (10.8 MW)) in a wide range of head pressure, the high wellhead pressure, figure 8 B facilitates the immediate operation of the well. During the tests performed, the well produces a biphasic fluid from the formation.

4.2 Well PGP-83

After 13 months after the end of its drilling, the second evaluation was extended for 15 days, this shows an intermediate head pressure at high with respect to the wells of the U2PGF which increase when it is restricted with ranges ranging from 7.94 to 14.24 bar a. The enthalpy of the total fluid producing is 1202 kJ / kg. The well produces a total mass of up to 44 kg/s being one of the lowest in the field, which coincides with the low injectability index (1.0 l/s/bar) presented, could indicate that an area with low permeability away of the main sources of heat and faults, a comparison of the mass flow produced is presented in Figure 10. Prior to the start of the first productive evaluation of this well, only the static temperature and pressure profile was performed, Figures 8A, due to some difficulties during the logging operations, the dynamic temperature and pressure profile could not be performed during the opening of 2018, the static profile showed a very stabilized area with a maximum temperature of 262 °C at 1600 m deep, Castro, S. (2018) b, similar to the temperature reported by the Na-K-Ca geothermometer near 260 °C. After 13 months after completion of drilling. The results obtained from the test indicate: the productive characteristics of the PGP-83 are acceptable, and its incorporation into the production system would allow to provide approximately 11 kg/s of steam (5.2 MW) at maximum flow. This produces biphasic fluid from the formation at both maximum and minimum flow; However, it is interesting to note that the enthalpies tend to be lower when passing from maximum to minimum flow, opposite to what commonly occurs in the wells, this may be due to the domain of areas of greater liquid flow in higher areas within the reservoir that they are perceived in the restricted condition of the well, which decreases the supply of steam causing the enthalpy increase and therefore the opposite effect occurs. Also, the high wellhead pressure, figure 8 B facilitates the immediate operation of the well.

4.3 Well PGP-51

The first evaluation was extended for 15 days, after 11 months after completion of its drilling, the PGP-51 and in general the PL-11 shows an intermediate head pressure with respect to the wells of the U2PGF which increase when it is restricted with ranges ranging from 9.24 to 12.44 bar a, Figure 11A. The enthalpy of the total fluid producing is 1028 kJ/kg. Prior to the start of the first productive evaluation of this well, the static temperature and pressure profile was performed. The static and dynamic profiles made during the evaluation, Figures 8A and 9A show that the static and dynamic temperature was very homogeneous with a maximum of 239 °C from 1000 m deep, Castro, S.(2018)c, confirming the thermal stability of the well, similar to that reported by the quartz geothermal meter near 240 °C. The productivity index is high: 28.6 kg/s/bar measured at 1700 m, it can produce a total mass of between 57-134 kg/s, presenting the greatest total mass of the wells of the field, a comparison of the mass flow is presented in Figure 10. With these parameters, it is determined that: PGP-51 has very good production characteristics and its incorporation into the Pailas 2 production system would allow to provide approximately 23 kg/s of steam (10.6 MW). The different operating conditions used during the test the well produced saturated fluid since the formation. This well has a reduced operating range, figure 11 A; the wellhead pressure in static condition, figure 8 B indicates that after some years of operation it may require stimulation for starting.

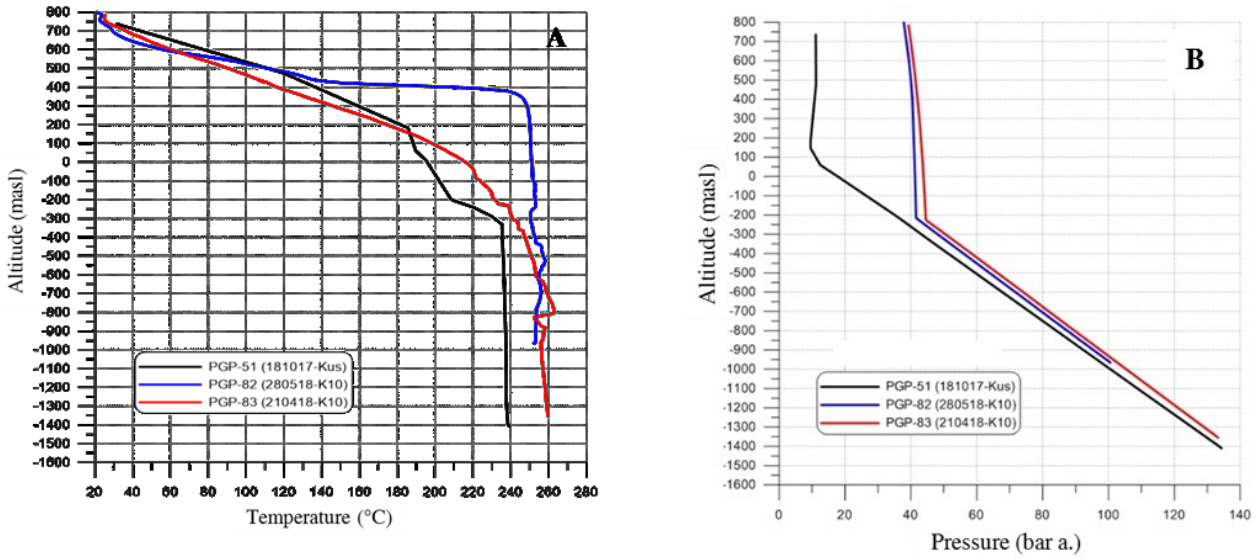

Figure 8: Graphs for Static temperature(a) and Pressure (B) of the wells PGP-51, PGP-82, PGP-83

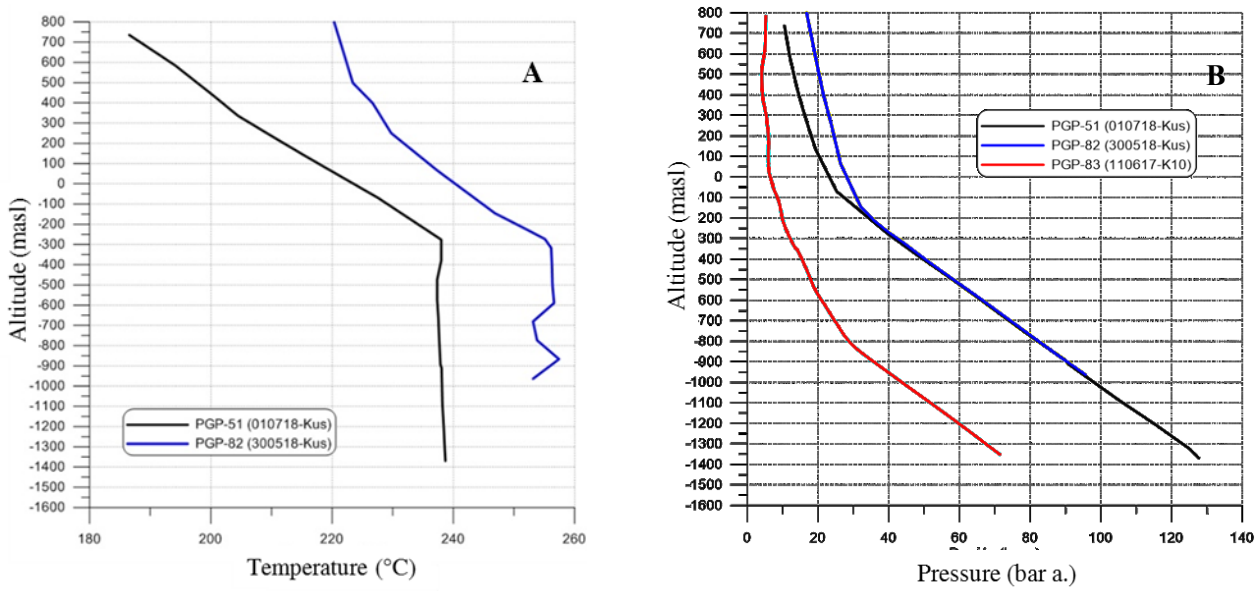

Figure 9: Graphs for dynamic temperature(a) and Pressure(B) of the wells PGP-51, PGP-82, PGP-83

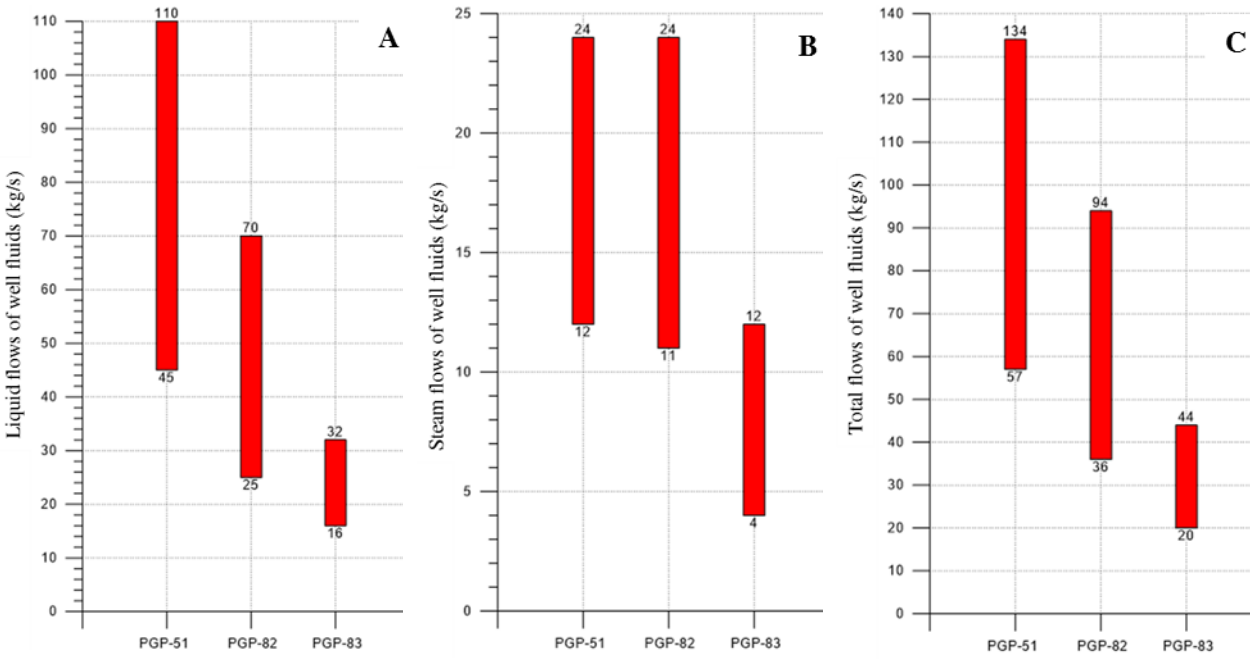

Figure 10: Comparative graphs of Liquid Flow rate (A), Steam Flow rate (B) and Total mass rate of the wells PGP-51, PGP-82, PGP-83

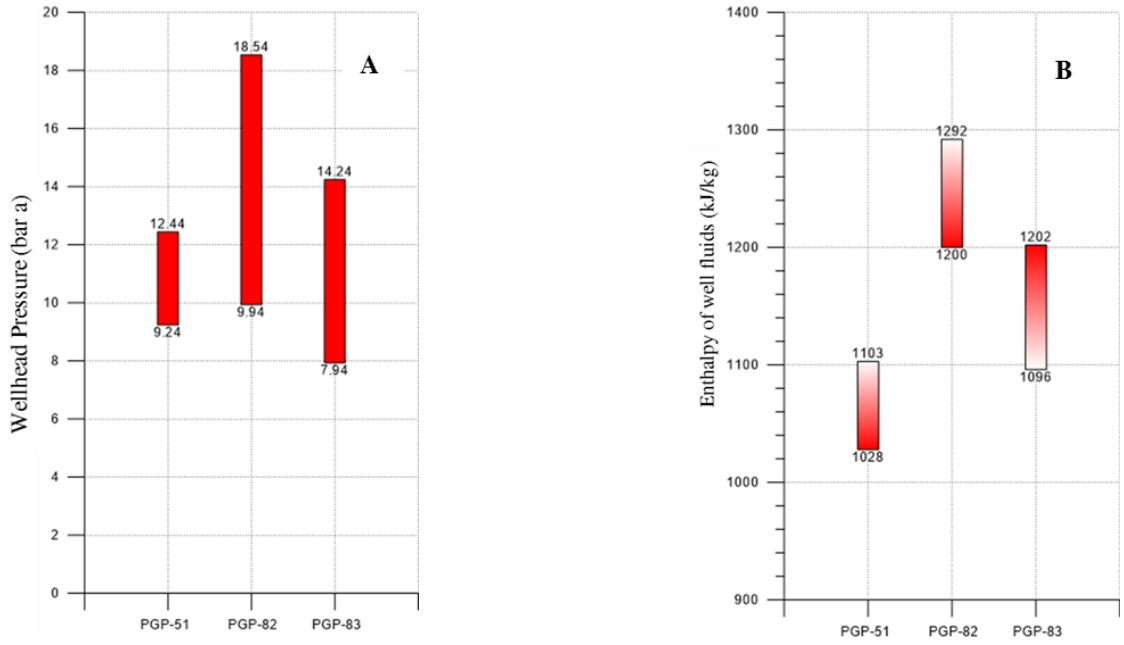

Figure 11: Comparative graphs of wellhead pressure (A) and Enthalpy (B) of the wells PGP-51, PGP-82, PGP-83

5. CONCLUSIONS

The main objectives of this publication were to show a preliminary characterization of the geological-chemical-thermohydraulic and productive characteristics of the geothermal fluids of Unit 2 of the Las Pailas geothermal field based on the first measurements made in the field. The conclusions are as follows:

The geothermal reservoir of the U2PGC is developed on the geological formations of the Bagaces and Aguacate Group, where the first one overlaps the second. These are characterized by presenting secondary permeabilities along fractures mainly, other permeabilities found were through the lithological contacts in the upper part of the BG. These units are shared by the U1PGC geothermal reservoir, however this is defined and delimited by the San Vicente boiler, while U2PGF is outside this, both reservoirs are connected by major faults that cross the area and serve as hydraulic channels for the fluid transit The reservoir of U2PGC is a dominant liquid with Na-Cl type fluids of neutral pH, however areas of low acid pH domain with higher sulphate content have been found, possibly associated with the paragenesis of acid mineralogy, as seen in the PGP-83.

The chlorides vs. enthalpies diagram allowed to identify variations in salinity and caloric content between the wells of the field which were grouped into 3 main groups, group A represented by the PGP-82 that has the lowest salinity (conductivity: 21000 µS / cm , Cl: 7150 ppm), but of slightly higher enthalpy content which is reflected in the high temperatures recorded both by geothermometry (260 ° C) and in dynamic and static temperatures (256-258 ° C), which provides very Good production conditions providing a vapor mass of 24 kg / s of steam (10.8 MW). The PGP-83 represents group B shows an intermediate salinity, greater than that of PGP-82 (conductivity: 21600 µS / cm, Cl: 7400 ppm). The similarity shown between this well and those represented for Pailas I (PGP-03 and PGP-17), suggests that both fields share fluids from the same reservoir isolated by lithological and geomorphological barriers, but connected through important faults that promote permeability of fluids between the different areas of the reservoir and could be partially differentiated by different mixing ratios. The caloric content of these wells is very similar to group A, the static temperature is 262 ° C which is within the range recorded for the Na-K-Ca 257-266 ° C geothermal meter; Although it has a low index of injectability and generated steam mass, the production parameters are acceptable, providing 11 kg / s of steam (5.2 MW) to the system.

Group C represented by PGP-51 has different characteristics than groups A and B, show a high salinity (conductivity: 24000 µS / cm, Cl: 8200 ppm) and a lower caloric content evidenced at a temperature close to 240 ° C calculated with both geothermometers and static and dynamic profiles. Due to the orientation of this well to the northwest, it crosses the caldera of San Vicente and directs the wells towards the area of Pailas I, the thermohydraulic chemical characteristics suggest evidence of mixing with the reinjection fluids of Pailas I, which present a superior salinity and generates an enrichment in the chemical species of the fluids.

This field has high temperatures and significant concentrations of silica, being higher in Pl-13 where PGP-83 is located where below the separation temperature are on the line of silica saturation, this issue should be addressed during the first months of operation with constant monitoring. In the case of certain wells with the possibility of calcite embedding such as PGP-82, the calcium carbonate inhibition system widely used in the producing wells of the Alfredo Mainieri geothermal field will be implemented.

At the regional level, the characteristics of the fluids of the U2PGF wells show a similarity with the fluid chemistry shown in Las Pailas I and in the Borinquen Geothermal Field while they depart considerably from the salinity reached by the reservoir associated with the Miravalles Volcano in the wells of the AMGF.

According to the different exposed data analyzed for only 3 of the 12 producing wells, a geochemical and thermohydraulic variability of the reservoir was found, which has been addressed during its design and development, and will continue its monitoring with the start of commercial exploitation. It can be affirmed that most of producing wells of Las Pailas 2 (U2PGF) show very favorable productive conditions, guaranteeing the flexibility that is required for the sustainable exploitation of the geothermal reservoir and generation of 55 MW gross.

REFERENCES

CENCE (2018). Informe Anual 2018- Generación y Demanda- Informe Interno- .San José, Costa Rica.

Castro, S. (2018)a. Informe de la producción del PGP-82 del 28 de mayo al 14 de junio de 2018. Área de Geociencias. Grupo de Ingeniería de Yacimientos. Campo Geotérmico Pailas 2. (Informe Interno). Bagaces, Costa Rica.

Castro, S. (2018)b. Informe de la producción del PGP-83 del 26 de abril al 25 de mayo de 2018. Área de Geociencias. Grupo de Ingeniería de Yacimientos. Campo Geotérmico Pailas 2. (Informe Interno). Bagaces, Costa Rica.

Castro, S.; Torres Y. (2019): Análisis de variables del yacimiento y estrategias de explotación etapa inicial Las Pailas 2. Instituto Costarricense de Electricidad. Centro de Servicio Recursos Geotérmicos. Área de Geociencias. Informe interno. 59 pp.

Chavarría, L., Mora, O., Molina, F., Hakanson, E.C.,Galvés, M., Rojas, M., Murillo, A.(2010): Geologic Model of the Pailas Geothermal Field, Guanacaste, Costa Rica, Proceedings, World Geothermal Congress, Bali, Indonesia, 4 pp.

West JEC (2013). Estudio Preparatorio para el Proyecto de Desarrollo Geotérmico de Guanacaste en Costa Rica. Las Pailas II. Informe Final. Febrero 2013. Agencia de Cooperación Internacional del Japón (JICA) - Instituto Costarricense de Electricidad(ICE). 346 pp.

ICE (2015). Servicios de consultoría para el diseño y supervisión de las obras bajo el préstamo sectorial para el desarrollo geotérmico de Guanacaste (Las Pailas II)- Informe Interno- San José, Costa Rica.

ICE (2017)a: Informe control geológico de la perforación del pozo direccional PGP-82. ICE-NIC. Centro de Servicios Recursos Geotérmicos. Campo Geotérmico Pailas 2. (Informe Interno). Galvéz O., M. & Herrera C., D. Bagaces, Costa Rica.

ICE (2017)b: Informe geológico del pozo PGP-83. ICE-NIC. Centro de Servicios Recursos Geotérmicos. Campo Geotérmico Pailas 2. (Informe Interno). Acuña A., O. & Mora P., O. Bagaces, Costa Rica.

ICE (2017)c: Segunda actualización del Modelo Geológico del Campo Geotérmico Pailas. Instituto Costarricense de Electricidad. Centro de Servicio Recursos Geotérmicos. Área de Geociencias. Grupo de Geología. Informe interno. 48 pp.

ICE (2017)d: Informe control geológico de la perforación del PGP-51. ICE-NIC. Centro de Servicios Recursos Geotérmicos. Campo Geotérmico Pailas 2. (Informe Interno). Castro Z., S. & Hakanson G., E. Bagaces, Costa Rica.

ICE (2019). https://grupoicecr.com/Noticias.

IGME (1985). Análisis Metodológico de las Técnicas Geoquímicas Empleadas en Prospección Geotérmica. Ministerio de Industria y Energía-Secretaría de la Energía y Recursos Minerales España. 417 pp.

Fournier, R.O., (1979): Geochemical and Hydrologic Considerations and the use of Enthalpy-Chloride diagram in the Prediction of Underground Conditions in Hot Spring Systems. *Journal of Volcanology and Geothermal Research*, 5, 1-16.

Janzen, D. (2017): SAPI for Geothermal Development Loan: Study on improvement of Environmental Monitoring methodologies for geothermal development in Costa Rica Agreement #0328497.-Internal Report-. University of Pennsylvania, Philadelphia, PA.

Keenan, J.H., Keyes, F.G., Hill, P.G. and Moore, J.G., (1969). Steam Tables. (International Edition - Metric Units). Wiley, New York, N.Y.

MIDEPLAN (2010). Gobierno de Costa Rica: Plan Nacional de Desarrollo 2011-2014 “María Teresa Obregón Zamora”. San José, Costa Rica.

Vega, E., Chavarría, L., Barrantes, M., Molina, F., Hakanson, E.C. and Mora, O., (2005): Geologic model of the Miravalles Geothermal Field, Costa Rica, *Proceedings*, World Geothermal Congress, Antalaya, Turkey, CD, 5 pp.