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

Geochemical Assessment of the San Jacinto Tizate Geothermal Field, Nicaragua

Gunter Gámez

San Jacinto Tizate, León, Nicaragua

Ggamez@polarisgeothermal.com

Keywords: Giggenbach, enthalpy, isotope, mineral equilibrium, chloride

ABSTRACT

The Geothermal Field San Jacinto Tizate is in the western part of Nicaragua, 75 km north from the capital, with an area of 6 km^2. It currently has an installed capacity of 77 MW. The reservoir of the Geothermal Field is liquid dominant with temperatures in the range of 227-291 °C, determined through deep logs. As the geothermal resource is exploitered, chemical changes are observed in the reservoir and, therefore, it is important to characterize and interpret the geochemical evolution of the Geothermal Field.

An evaluation of the reservoir chemistry is presented, based on geochemical methods, to analyze and interpret the different processes that affect the reservoir. The reservoir engineering area oversees processing and analyzing the chemical data obtained from monitoring the field, and for this evaluation an average of the data obtained was made every six months.

An individual interpretation was made for each well and it was possible to identify wells that present processes such as cooling by boiling in the nearby areas and, in some cases, furthest away from the feeding zones of the wells, with this it is inferred that there are different thermal and hydraulic characteristics in the different zones of the geothermal reservoir. In addition, there are wells that are in equilibrium with respect to the analysis of E_{mea}, E_{NaKCa} and E_{SiO2}, which indicates that there are no extreme temperature changes around the reservoir and well feed.

The Giggenbach diagram shows the evaporation succession process at the beginning of production of some wells, as an explanation for the excess steam found in certain areas of the field (except for wells SJ6-1 and SJ9-1, which at the beginning present an infiltration of lower temperature waters).

In the analysis of gases with the FT & HSH Diagram, changes were observed such as: increase in the steam fraction and decrease in temperature in the wells, decrease in the steam fraction with an increase in temperature, constant behavior of the steam fraction with increase in temperature, among others. These are indicative of processes that occurred in the wells whose reflection in the gases was of great importance for the interpretation.

Through the use of isotope, chloride and enthalpy diagrams, mineral equilibrium and N_2-He-Ar Giggenbach triangular diagram, an integrated interpretation was made that was related to the individual interpretation of the evaluated wells, resulting in the identification of three important zones of the reservoir: zone of ascent of hot equilibrium fluids in enthalpies and conditions close to boiling point; transition zone reflecting conditions of the directions of movement of fluids from the reservoir to their discharge, and a zone of influence of lower temperature water indicative of a border zone of the exploitable field.

1. INTRODUCTION

The San Jacinto Tizate Geothermal Field, Nicaragua, is in the western part of the country 75 km north of the capital, with an extension of 6 km^2.

The production started in 2005 with the SJ4-1 well with 5 MW generation in two counter-pressure units. To date, 12 producing wells and 6 reinjection wells have been drilled; 12 wells with dominant liquid characterization and 1 dominant steam well, has two condensing units, with an installed capacity of 77 MW.

Geothermal field San Jacinto Tizate has an analysis of geochemical parameters from 2005 to the present and carried out periodically in 4 samplings per year, with the purpose of monitoring and knowing the characteristics and changes occurred in each well of the field.

The investigation of this project was carried out for the interest of evaluating the geochemical state and the processes experienced by the dominant liquid producing wells of the San Jacinto Tizate Geothermal Field, making use of special tools for the processing of the parameters under study and with this being able to interpret the results obtained according to geochemical diagrams by wells (Giggenbach Diagram, Enthalpy Diagram and Gas Geothermometer Diagram), and by integrated geochemistry of the wells under study evaluated through the following diagrams: isotopes, triangular geothermometer N_2-He -Ar, activities mineral balance of fluids in the reservoir and Chloride & Enthalpy.

On the other hand, contribute to the identification of other processes that can be predicted or known, using geochemical analyzes and interpretations. As well as having an appropriate control and evaluation of the geothermal reservoir in order to improve efficiency and contribute to a sustainable management of the geothermal resource

2. GEOCHEMISTRY

Geochemistry has been evolving over time, which has increased its importance in the evaluation and development of geothermal resources. Deep drilling of new producing wells or re-injectors in most existing geothermal environments has provided a wealth of information on the chemical composition, evolution and thermal structure of geothermal reservoirs.

In the following text is described the different geochemical parameters by the evaluation of the geochemical state of the geothermal field San Jacinto Tizate, Nicaragua will be evaluated and interpreted.

2.1 Giggenbach Diagram NaKCa

The predominant process of alteration of the rock that accompanies the increase of potassium metasomatism in the thermal waters, which in turn means that of the four cations, Na, K, Mg and Ca, see figure 1. Potassium is eliminated from the Liquid phase to be absorbed in products of potassium alteration, Na, Mg and Ca. Add to the solution through the information of the corresponding minerals. The achievement of the balance of rock and water depends to a certain degree on the kinetics of the reactions of the production and deposition of individual minerals (Giggenbach, 1984).

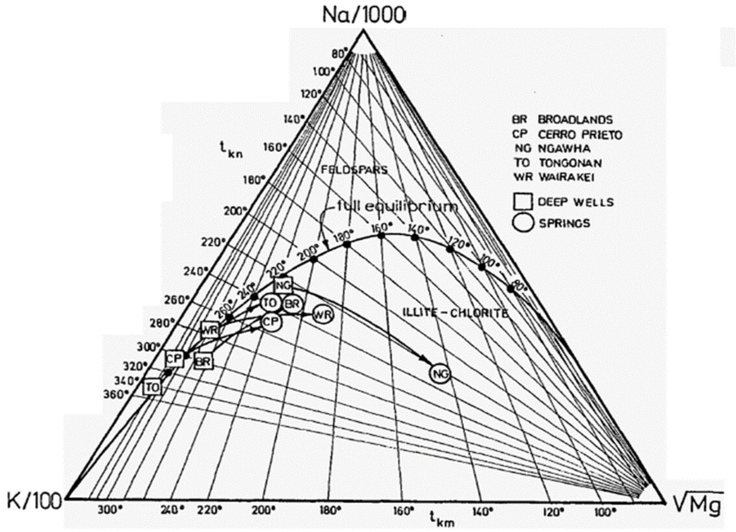

Figure 1: Relative contents of Na, K and Mg in geothermal waters. Evaluation of the balance temperatures of water rocks (Giggenbach, 1984)

2.2 Enthalpy Diagram

Characteristic changes in geochemical indicators over time provide information on reservoir processes in the wells under study. Quartz and NaKCa geothermometers combined with fluid enthalpy provide fluid status and temperature information at near and far distances from wells. (Truesdell, Lippmann, Quijano, & D'Amore, 1995)

2.2.1 Interpretation Criteria

$E_{med}=E_{NaKCa}=E_{SiO2}$: Indicates a fully liquid balanced reservoir liquid. Fast and slow geothermometers reactions are in equilibrium with the inlet temperature. There is no presence of excess steam and temperatures have not been affected by mixtures.

$E_{med}>E_{NaKCa}>E_{SiO2}$: It indicates boiling of the liquid during the trip to the well responding to a decrease in pressure at the bottom of the well. Boiling and temperature decreases near the well and causes heat transfer from the rocks to increase the values of E_{med}. SiO_2 is balanced so that E_{SiO2} decreases. The E_{NaKCa} by the slow reaction is not affected.

$E_{med}=E_{NaKCa}>E_{SiO2}$: The pressures are controlled by a constant pressure limit, the bottomhole pressures gradually stabilize and the boiling zone expansion slowly decreases and disappears. The E_{SiO2} is low because the boiling and temperature decreases.

$E_{NaKCa}>E_{med}=E_{SiO2}$: It results from a mixture with cold water near the well with re-equilibration of E_{SiO2}, but not E_{NaKCa}.

$E_{med}>E_{NaKCa}=E_{SiO2}$: Indicates liquid mixture balanced with steam formed by boiling away from the well.

$E_{NaKCa}>E_{SiO2}>E_{med}$: Indicates mixture of colder water with balanced liquid. The lower values of E_{SiO2} results from the rebalancing dilution and E_{NaKCa} is not affected. It could be a well with multiple entries.

$E_{med}=E_{SiO2}>E_{NaKCa}$: Indicates thermal advance of cold water E_{NaKCa} still retains the equilibrium memory at lower temperatures, although the liquid has been heated by a flow of hot rock. Chloride changes will indicate a hydraulic or chemical advance.

$E_{med}>>E_{NaKCa}>>E_{SiO2}$: It is an unusual pattern throughout the discharge of a very dilute brine, indicates high temperature condensed steam, this occurs in casing or separator and possibly in reservoir ducts. Condensation occurs with constant enthalpy and is not produced by cooling the fluid, but if there is a dilution of the brine with condensed steam which lowers the silica temperature.

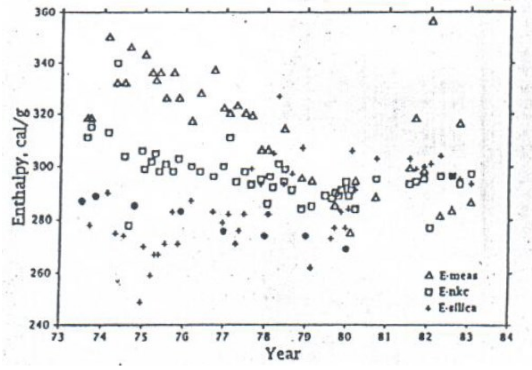

Figure 2: Enthalpy diagram (Truesdell, Lippmann, Quijano, & D'Amore, 1995)

2.3 Gas Diagram FT & HSH

in geothermal gases are of variable compositions, which can be observed over time that is affected by temperature variations in the reservoir. These thermal variabilities can be interpreted by a combined analysis of the time variation in the calculated values of the steam fraction "y".

<u>2.3.1 Interpretation Criteria</u>

- An Increase in temperature and decrease of steam fraction "y" may indicate a contribution fluid from a hotter and deeper source with a high liquid saturation.
- An increase in temperature and increase of steam fraction "y" may indicate apparent increase in temperature and steam source.
- A decrease in temperature and decrease in steam fraction "y" may indicate a local source of pure and low-temperature water with no gas content that does react, as in the case of reinjection or quick recharge.
- A decrease in temperature and increase in steam fraction "y": This situation is usually related to a decrease in the H2S/H2O ratio. This could be due to recharging as a result of the exploitation and boiling of a low-temperature fluid rich in gases. Due to its marginal position with respect to the main upstream zone of the field, it has suffered a relatively long residence time in the reservoir, or by a precipitation of sulphides caused by excessive local production with blockage in the main fractures. In this case the condensate residue is as rich in salts as it causes precipitation of higher amounts of sulfide than local production H_2S (D'Amore, 1991)

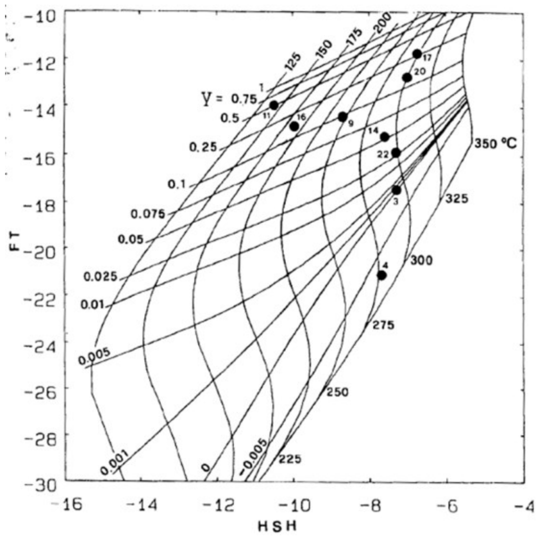

Figure 3: Diagram FT&HSH (D'Amore, 1991)

2.4 Diagram Isotopes of Fluids in the reservoir

Isotope are all atoms of the same type that have a different number of neutrons in the nucleus, which makes them heavier or lighter than the more abundant atom but retaining all the properties. The distinguishable characteristic will be mass or weight, related to its mobility. Electrons are responsible for binding atoms in chemical reactions and have a negligible weight while protons and neutrons in the nucleus give the weight to the atom. And because the absence or gain of a neutron in an atom is perceptible and measurable, isotopes will have different mobility which will cause the proportions relative to the sampling site, while the rest of the characteristics will be retained (complying with all physical, chemical, element association and mass and energy conservation laws.

Isotopes are very useful in geothermal systems for many aspects such as classification of fluid types: shallow, juvenile-mature, magmatic, etc. As well as, for the classification of the type of system present (dominant liquid or dominant steam). They have also been used in groundwater age dating (3H/1H), of course they are useful for determining the origin of water or its recharge (18O/16O, 2H/1H), and fluid movement (18O/16O, 2H/1H vs chemical geo-indicators such as chlorides), for grouping analysis in contrast to actual site location (D'Amore, applications of geochemistry in geothermal reservoir development, 1991).

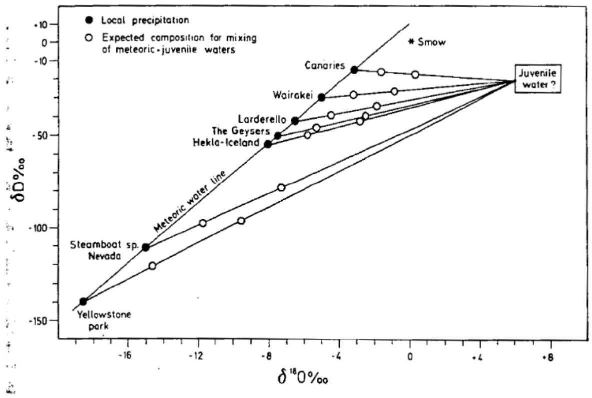

Figure 4: Isotope techniques in geothermal studies, an example of a mixture between local meteoric water and juvenile water in different proportions (D'Amore, 1991).

2.5 Triangular diagram of Giggenbach N_2-He-Ar

In the triangular diagram of He-Ar-N_2, three areas related to the three main components of the diagram are delimited:

A meteoric component, represented by air-saturated groundwater, which contributes to N_2 and Ar, in molar ratio of 38 or greater, due to the drag of air bubbles. The Ratio of He/Ar <0.001

A magmatic component, characterized by an increase in N_2/Ar proportions of around 800, but proportions less than 200 have been observed. These very high Ratios of N_2/Ar appear to be typical of "andesitic" gases, these ratios are usually lower. The He content of the magmatic component is considerably higher than that of the meteoric component, (He/Ar-1.0).

A crust component composed largely of He radiogenic. He-4 content can be expected to increase by increasing the residence time of gases in the crust.

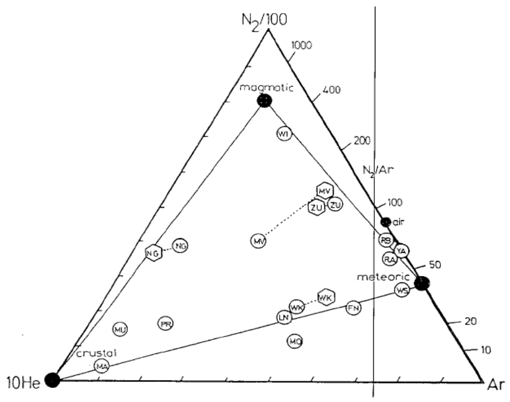

Figure 5: Relative contents of N_2, He and Ar in geothermal gas discharges on molar base (volume) (D'Amore, 1991).

2.6 Fluid Mineral Balance Diagram in reservoir

Activity diagrams are just one way to represent the relationship between minerals and fluids in geothermal systems and to compare the sets of alterations observed in the geothermal system. They are also useful for discussing the mineralogical effects of cooling or boiling hydrothermal solutions.

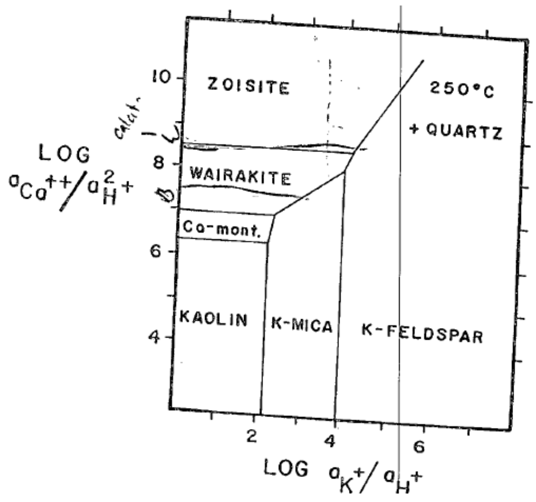

Figure 6: Activity diagram for the main phases of the system, CaO - Al_2O_3- K_2O-H_2 at 250oC (Truesdell, Lippmann, Quijano, & D'Amore, 1995)

2.7 Diagram Chloride & Enthalpy

Hot springs may arise where chlorinated water from the depth reaches directly to the surface, but in many systems an underground mixture of fluids is produced to produce hybrid fluids or mixtures of cold water, steam, vapor loss and fluids from cold aquifers.

To obtain hydrological information from hot springs and wells, we need to be able to recognize these processes and at least semi-quantitatively determine the relative proportions of each component of the mixture. The mixing diagram relates the enthalpy, phase and concentration of chloride (Truesdell et al, 1984).

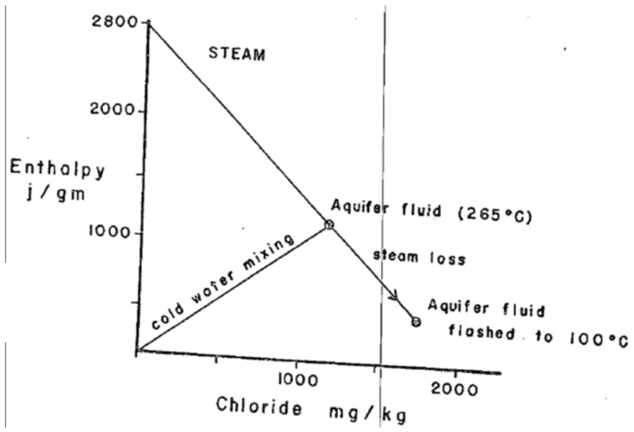

Figure 7: Typical enthalpy-chloride mixing diagram (Truesdell et al, 1984).

3. EVALUATION OF THE GEOCHEMICAL EVOLUTION OF WELLS

3.1 Enthalpies Wells

The SJ4-1, SJ5-1, SJ6-2, SJ12-2 and SJ12-3 it can be observed that $E_{mea} > E_{NaKCa} = E_{SiO2}$ which indicates at the beginning of its production was excess steam, over time decreasing to such an extent that its fluid comes only from a liquid zone. The SJ4-1 in 2018 the $E_{mea} > E_{NaKCa} > E_{SiO2}$ indicating a boiling process in the fluids as they move towards the well. In wells SJ5-1, SJ6-2, SJ12-2 and SJ12-3 in 2018, a localized boiling cooling process is observed when the fluid enters the well.

The wells SJ6-1, SJ6-3 and SJ9-1 are low enthalpy, it can be observed that $E_{mea} = E_{NaKCa} = E_{SiO2}$ which indicates that wells completely liquid of low temperature. In the case of SJ6-1 it observed mixture with fluid of less temperature.

The well SJ9-4 it can be observed that $E_{NaKCa} > E_{mea} = E_{SiO2}$ this suggests that there may locally boiling in the well feeding zone with cooling reflected in the enthalpy of quartz and the measured enthalpy.

The SJ9-3 is a cyclic well of dominant liquid. Wells SJ12-4 and SJ12-5 are new and are in the equilibrium process.

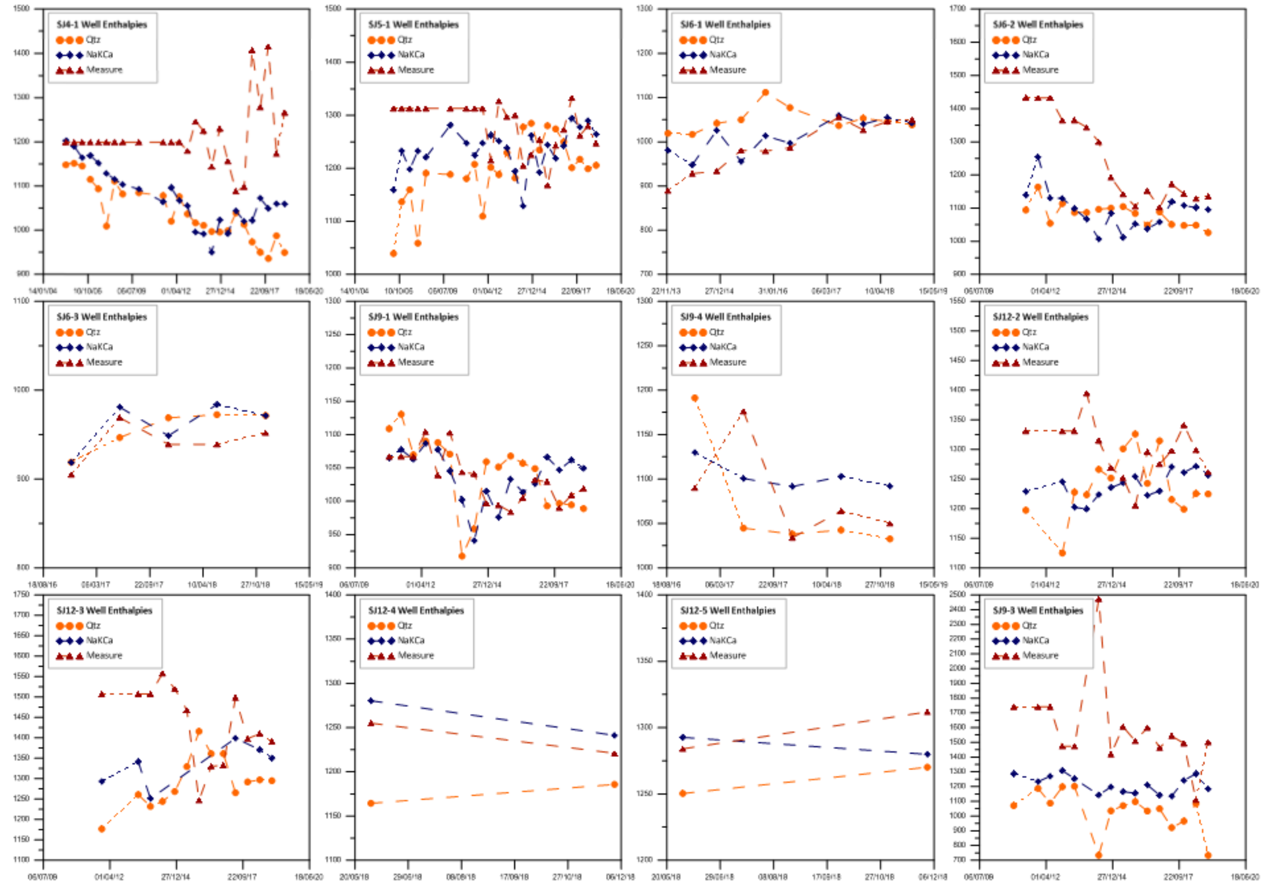

Figure 8: enthalpy of all the producing wells of the Geothermal field San Jacinto Tizate

3.2 Giggenbach Diagram Na-K-Mg

Figure 9 identifies the lowest temperature wells (SJ4-1, SJ6-1, SJ6-2, SJ6-3, SJ9-4 and SJ9-1) and those with the highest temperature (SJ5-1, SJ12-2, SJ12-3, SJ12-4 and SJ12-5). Well SJ6-3 is the least hot well and therefore furthest from the balance line since there is a greater evaporation process. In the case of the SJ12 wells, they are close to the equilibrium line due to their high temperature and the boiling process that occurs locally.

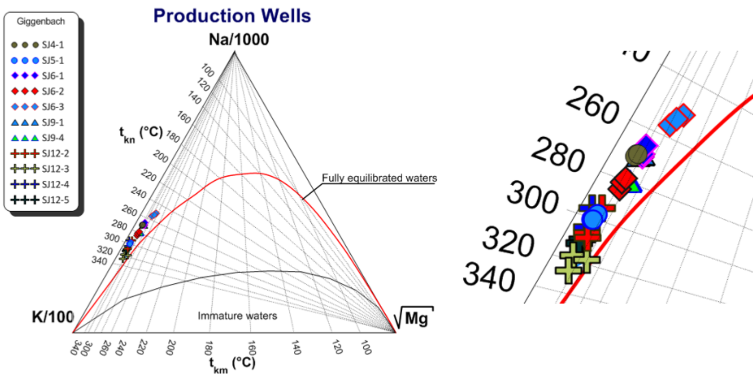

Figure 9: Giggenbach diagram of all production wells

3.3 FT & HSH Diagram

Wells SJ6-1, SJ6-3, SJ9-1 and SJ9-4 (see figure 10) over time have been increasing their temperature and decreasing their vapor fraction which indicates a greater contribution of a hotter and deeper fluid.

The SJ4-1, SJ5-1, SJ6-2, SJ12-2 and SJ12-3 over time have behaved in the same way increasing their temperature and vapor fraction which is an indication of an increase in their source of steam.

The SJ12-4 and SJ12-5 have increased their temperature and decreased their vapor fraction indicating a contribution of a fluid from a hotter and deeper source

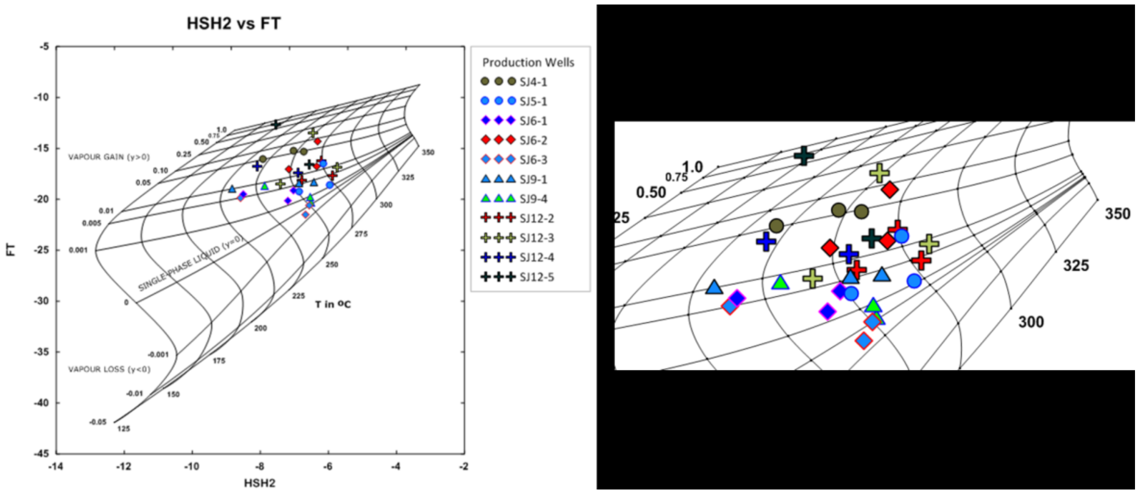

Figure 10: FT & HSH of all production wells

4. INTEGRATED ASSESSMENT OF WELLS

4.1 Isotope Diagram

In figure 11, the isotopic diagram for producing wells SJ4-1, SJ5-1, SJ6-2, SJ9-1 and SJ9-3 is presented, the other wells are not presented because isotope data is not available.

The wells are located in such a way that a characteristic line can be observed, qualifying as a line of isotopic evaporation of the field, this is because the isotopes have evolved as they move from the fluid ascent zone of the reservoir to the discharge zone (wells SJ6-2 and SJ4-1) which shows an increase in concentration (enrichment) this varies in each well. In the case of well SJ5-1 it has the lowest values compared to the other wells, this refers to a possible upflow zone of the geothermal system, because they may come from the mother fluid. This is reinforced with the enthalpy & chlorides graph where all producing wells are located.

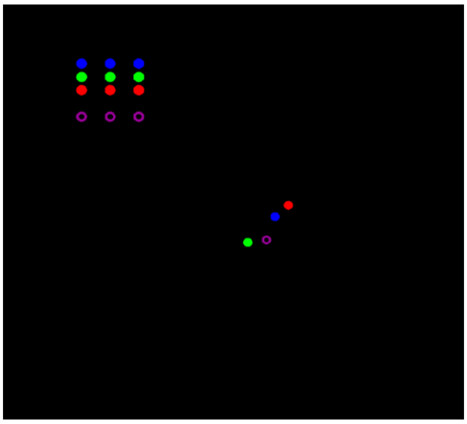

Figure 11: Diagram Isotope

4.2 Enthalpy & Chloride Diagram

In the enthalpy & chloride diagram (figure 12), well SJ5-1 is located in an area of high enthalpy and low relative chloride content, which is characteristic of fluids that are close to the ascent zone of the geothermal reservoir, in that same zone are the wells SJ12-2, SJ12-3, SJ12-4 and SJ12-5, which could correspond to the same upflow zone. In the case of wells SJ6-1 and SJ6-3, they are located in the dilution zone characterized by a low content of chlorides and enthalpy. Wells SJ6-2, SJ4-1, SJ9-1 and SJ9-4 are located in the steam loss zone. This correlates with those mentioned above with the isotopes (SJ4-1, SJ6-2 and SJ9-1) and indicates that these fluids already have a certain distance away from the ascent zone.

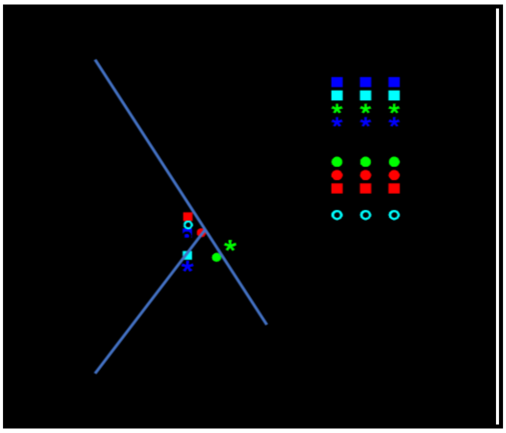

Figure 12: Enthalpy & Chloride Diagram

4.3 Giggenbach Diagram N2-He-Ar

In the gas diagram of Giggenbach (see figure 13) it is observed that wells SJ4-1, SJ6-1, SJ6-3 and SJ9-4 are in a tendency to an area with meteoric influence, indicating that they are fed by a fluid younger or found at a greater distance from the heat source. In the case of wells SJ5-1, SJ12-2, SJ12-4, SJ12-3, SJ12-5 and SJ9-3 they are located towards an area with magmatic influence because possibly the upflow that was located in the area SJ5-1 (with the isotope diagram the upflow comes from the area of SJ12), this also indicates that they are closer to a magmatic source fluid or heat source, also it is observed that as the wells move away from this zone they reduce their magmatic content as it happens with the well SJ5-1 as it is indicated in figure 13 by the arrow with green color .

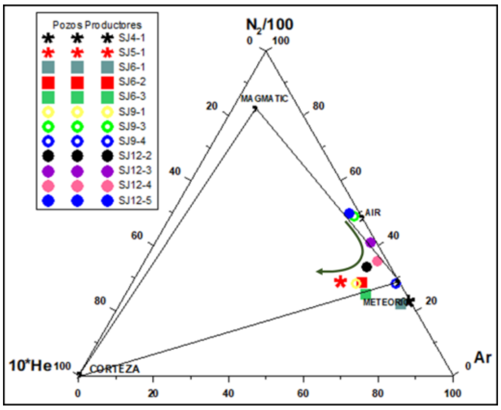

Figure 13: Giggenbach diagram N2-He-Ar

4.4 Diagram of Mineral Balance of Fluids in Reservoir

In the figure 14 shows that in the case of SJ12 wells there is a tendency to be located in the area of potassium mica which corresponds to its proximity to the heat source since its mineralogical association reflects the correlation with a primary mineral characteristic of volcanic systems such as those present in the area; wells such as SJ6-1, SJ6-3 and SJ9-4 are located separately from the other wells in the Epidote area (high temperature ore), which is somewhat contradictory since it was previously seen that the zone of these wells are cold and with traits of influence of lower temperature waters, however it is possible that the epidote was formed in older times in which there was a higher temperature and therefore it is a cooling zone.

The diagram shows some important changes in some wells from the beginning to the present of its operation, which are discussed below:

In the case of well SJ12-3 it is not observed that its mineralogy has changed, compared to SJ12-2 that it has undergone a significant displacement; Both wells according to the enthalpy analysis experienced an excess of steam at the beginning of their production and currently in the two a localized boiling cooling process occurs, that process is observed to affect the mineralogy of SJ12-2, otherwise to SJ12-3 probably because it is located closer to the heat source, and these processes do not change their mineralogy.

In the case of the SJ5-1 well, a movement towards K-mica is observed due to an increase in pH due to a process of degassing due to the loss of steam that is possibly transported to wells SJ6-2 and SJ4-1. The SJ6-2 well was moved from the K-mica zone to the equilibrium zone between the K-mica and the wairakita, this movement is the product of the excess steam in which it was at the beginning of the production, which with the time and the extraction effect was diminished until nowadays it reaches a boiling cooling process as mentioned earlier in the enthalpy section.

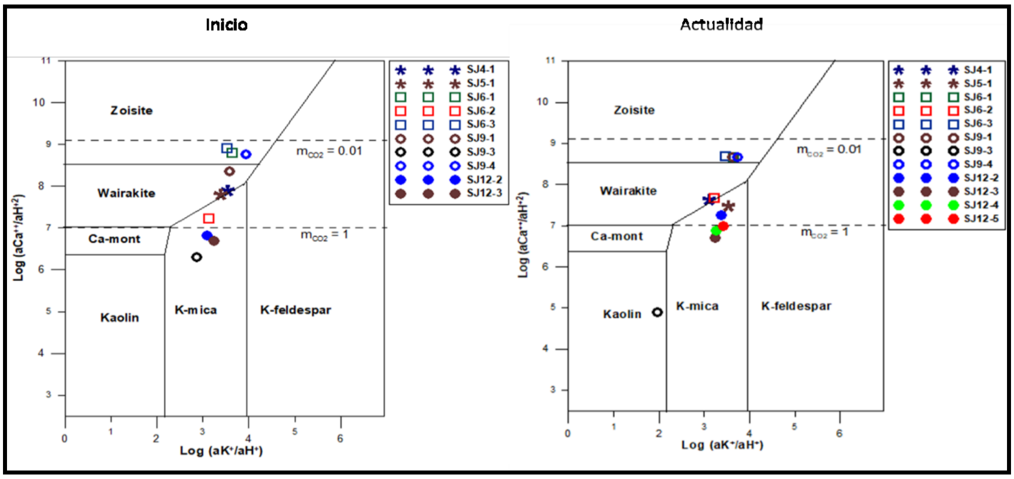

Figure 14: Diagram of mineral balance of fluids in reservoir

5. INTEGRATION OF FINDINGS.

Based on the previous analysis, Figure 38 presents the areas of the main findings found through the evaluation of the wells, in which there are three zones with similar processes and characteristics which are described below:

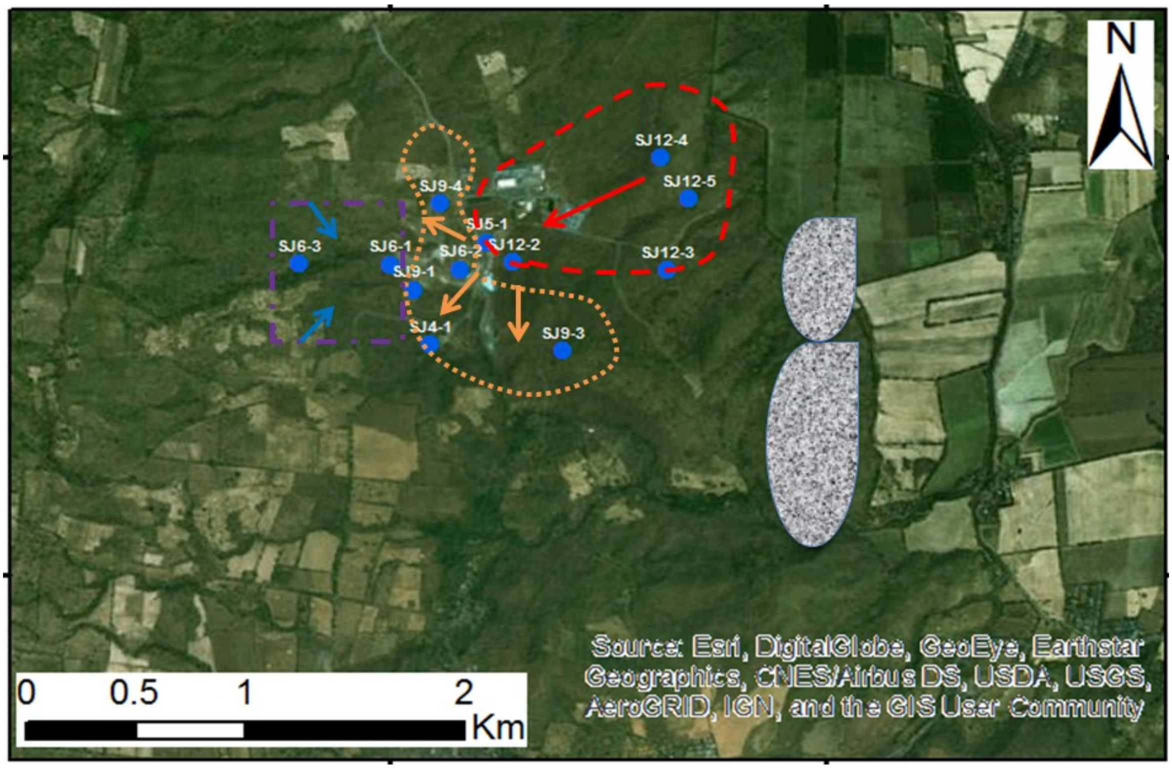

Figure 15: Geochemical zoning of the San Jacinto Tizate Geothermal Field.

Hot fluid ascent zone: Delimited in red in figure 15, this area includes wells SJ12 and SJ5-1 which initially have excess steam caused by boiling (more visible in well SJ5-1) and subsequently they have presented a balance of enthalpies evolving in recent years to the reflection of localized boiling (less pronounced than at the beginning), their isotopic contents, chlorides, gases and mineralogical assembly indicate that these are the most complete fluids in the field, which are characteristic of an upflow zone; However, it should be mentioned that the condition of said fluids is very close to the boiling point, that is to say that although they have a high temperature the pressure or hydraulic load is not sufficient to bring the fluids to the condition of compressed liquid whereby boiling is generated located and the management of the operating pressure of the well is important to control the boiling in it.

Transition zone: Delimited in orange in figure 15, this zone comprises wells SJ9-1, SJ9-4, SJ4-1 and SJ6-2 which have more positive isotopic conditions with higher chloride contents, this is characteristic of fluids that move away from the ascent zone and therefore experience loss of steam evidenced in a more pronounced boil in some cases, in turn indicate the directions of movement of the reservoir fluids towards their discharge. It is important to note that the SJ9-1 well shows some deviation from this behavior in some analyzes since it is close to an area where there is an entry of lower temperature fluids, which is described in the following paragraph. It is important to note that the SJ9-4 well is included in this group since its enthalpy of Na-K-Ca reflects that the fluids of this well come from an area of higher temperature and therefore these are already moving away from the ascent zone

Zone of influence of cold fluids: Delimited in purple color in figure 15 this area comprises wells SJ6-1 and SJ6-3, this presents conditions of lower geotemperatures and evidence of lower temperature fluids reflected in their relative contents of gases, chlorides and enthalpies, this is indicative of a border area of the exploitable field and which in turn could be recharging the reservoir since the hydraulic load found in this area is high and the fluids present in it are located in the condition of compressed liquid.

6. CONCLUSIONS

The research on the evolution of the geochemical state of the San Jacinto Tizate Geothermal Field, proved to be a primary basis for the characterization of the reservoir, all this through continuous monitoring of the field and a database of important geochemical parameters, used as a tool for their respective interpretation and determination of changes in time according to the processes experienced by the reservoir produced by the exploitation of the geothermal resource.

Through the geochemical interpretation of the available information it was determined that wells such as SJ4-1, SJ5-1, SJ6-2, SJ9-3, SJ9-4, SJ12-2 and SJ12-3, present evidence of boiling which in some cases occur locally in the closeness of the well feeding zone and in others to a greater extent generating excess steam in some areas of the reservoir, this suggests the existence of an important vapor layer in areas of the field where the structural geological conditions allow segregated movement of steam (phase segregation phenomenon). The existence of wells in equilibrium was verified with respect to the analysis of E_{mea}, E_{NaKCa} and E_{SiO2}, which are wells SJ6-1, SJ6-3, SJ12-4 and SJ12-5, was also verified in the field, indicating that there are no extreme changes in temperature and pressure due to the extraction around its feeding zones, this is due to the fact that the first two cases have lower temperature water recharge and the last two are very close to the area of the fluid ascent zone , conditions that give them a quick supply of fluids in response to extraction.

Overall, the behavior observed in the Giggenbach diagram reflects the condition of high temperature evaporated fluids, especially at the beginning of production where there was an excess of steam favored by which field was not exploited at that time, currently observe a boiling cooling caused by the exploitation of has occurred over time. Except for wells SJ6-1 and SJ9-1 that present an infiltration of water with lower temperatures, which is because these wells are located far from the heat source.

In the analysis of integrated results of wells according to the behaviors shown in the Isotope Diagrams of fluids in the reservoir, Giggenbch N2-He-Ar triangular diagram, Chloride & Enthalpy Diagram, it can be highlighted that there are three behavior zones in the reservoir area:

- Upflow zone characteristic of enthalpy balance and conditions near the boiling point.
- The transition zone that indicates conditions of the directions of movement of the reservoir fluids towards their discharge.
- Zone of influences of cold fluids of lower temperature, indicative of a border area of the exploitable field.

REFERENCES

D'Amore, F. (1991). Applications of geochemistry in geothermal reservoir develpment. *Series of technical guides on the use of geothermal energy*, 224-228.

D'Amore, F. (1991). Gas geochemistry as a link between geothermal exploration and explotation. *Series of technical guides on the use of geothermal energy*, 95-112.

Giggenbach, W. (1984). Graphical techniques for the evaluationof water/rock equilibration conditions by use of Na, K, Mg and Ca contents of discharge waters. *NZ Geothermal*, 37-38.

Truesdell et al. (1984). Fluid-mineral equilibria in hydrothermal systems. *Economic geology*, 22-26.

Truesdell, A., Lippmann, M., Quijano, J., & D'Amore, F. (1995). Chemical and physical indicators of reservoir processes In explolted high-temperature, liquid-dominated geothermal fields. *World Geothermal Congress*, 2-4.