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Geochemistry Exploration in Tectonic Systems

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ABSTRACT

Honduras, it`s located in Central America, it doesn`t possess an active volcano system, in fact no volcanos at all, nonetheless it has various superficial geothermal manifestations related to low and high enthalpy. The superficial manifestations found here are: hot springs, fumaroles, steam soils and mud, located in the northwest, center and south of the national territory.

Particularly characteristics blossom here as oppose to the rest of Central America; this is due to the geothermal sources which are directly related to tectonic systems and associated to geological faults, in other words, the continental plates interact. And for the south zone, it exists a possibility of a subduction influence of Cocos and Caribbean plates.

The superficial manifestations located in the northwest zone, north and center, respond to the interaction of the North American and Caribbean plates and their related geological faults. The objective of these document is to present, by a field investigation, the geochemistry of the manifestations of heat sources associated to tectonic systems compared with the volcanic ones. Taking as an example known systems in the Central American region, making use of ionic and cationic analysis in the liquid and gas phase during tests in the laboratory.

1. INTRODUCTION

According to Alvarez, J. (2006), and the field studies done with the accompaniment of the Natural Resources and Geoscience Federal Institute of Germany (BGR) we can point out that the regional tectonism, and therefore the structural exhibits in the zone, is characterized by the interaction of different blocks that shape up Central America. As we know the north of Central America is define basically of the Chortís block. This block is separated by the Mayan block (or Yucatán), wielded to the plate of North America by a sinister shear zone which represents the northern border of the Caribbean plate. South east of the Chortís block it`s occupied by the Central American isthmus that unifies the Chortís block to South America. It is this isthmus which is formed by two blocks of smaller size, Chorotega and Chocó (Dengo, 1985) (also known as Panama block or Panama microplate (Fisher et al., 1994)). The Mayan and Chortís blocks are recognized as continental blocks, while the Chorotega and Chocó blocks are of unknown origin even though it is often appointed by affinity to oceanic or transitional blocks (Dengo, 1968). The Chortís block division from south Central America appears to happen because of the sinister shear zone (Santa Elena fault or Gatún (Berrangé et al., 1989; James, 2007)) and in some way is the Hess escarpment continuity which has been defined as sewed by some authors (Carr and Stoiber, 1977; Berangé et al., 1989).

The principal structures of the northern Central America are associated by the interaction of the above define blocks, and some other fewer ones that probably build up the Chortís block in its internal composition. That way, the Chortís block is the most remarkable structure along with other lithospheric plates involved in the deformation zone, the North American and Coco. The North American boundary – The Caribbean is a sinister shear zone which is functioning, as we seen, since the Paleocene era, so that overtime different structures associated to those boundaries have had a major or minor importance. Nowadays the Motagua fault seems to be the principal structure in the Chortís block system, nevertheless the structures are clearly marked in the silhouette, as the Chixoy, Polochic or Jocotán – Chamelecón (Figure 1), which indicates that its activity in recent times has been very important (Burkart et al., 1987; Gordon and Muehlberger, 1994) and could even be activated, which is probably the case for the Chixoy – Polochic (White, 1985). The Caribbean boundary – Coco is a subduction of the second plate under the first. The average velocity for both plates is between 70 and 90 mm/year in relation of the point along the Mesoamerican pit (DeMets, 2001). The Benioff zone which is define by its very clear seismicity, having a very high dip in the subduction under the Chortís block, reaching a maximum depth of 280 km. in seismicity. Deformations in the subduction effect over the Chortís block does not seem to be elevated, in spite of the level of seismicity in the zone, and the high velocity in conversion.

The associated faults to the study zones where the geochemistry was analyzed and directly related to the following geological faults:

Tear faults in intraplate: To the east of the Honduras depression there is a series of tear sinister faults with a parallel course to the North American boundary – Caribbean in the north of Honduras (Manton, 1987). Out of these there are three mayor faults: La Ceiba, Río Viejo and Aguán (Gordon y Muehlberger, 1994). Rogers and Mann (2007) recently studied these structures with submarine and earth data and describe it as crosswise slipping in transtensive surroundings, in other words, jointly with the existing drainage net near to the visible sinister jump it exists a normal jump which generates a “rift” morphology to the northern border of the Chortís block.

N120°E faults: This family of faults has been classically recognized in the Chortís block and was interpreted by Manton (1987) as right handed tear that has giving way to “pull-apart” basins. Anderson (1987) mapped the Lepaterique sheet (South East of Tegucigalpa), and even though he mapped this family of faults, he did not found any evidence of a jump in direction and were covered by quaternary lava flows in such a way that they could not be activated nowadays. Gordon and Muehlberger (1994) found faults of direction of the Comayagüa graben with pitch stretch marks 67°E, evidencing its normal character with a right handed component. For Gordon and Muelhberger (1994) these faults acted as normal within the Miocene era and they have been relieved by the N-S in the Quaternary era.

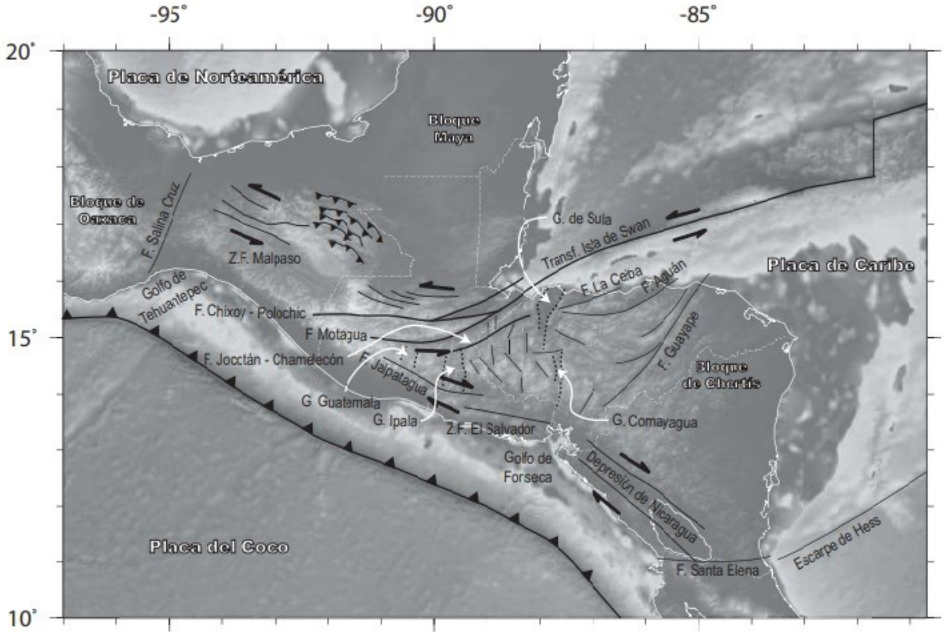


Figure 1: Map showing the location and also traces of the principals zones and structures mention in the text. (Alvarez J, 2006)

The nucleus of the Chortís block could be divided in three basic parts (even though these parts could be subdivided according to its morphological characteristics (Dengo, 1968; Marshall, 2007)): The western zone of the Chortís block, central and eastern area. As previously describe, the boundaries of these areas are marked by important tectonic accidents like the transforming-Motagua-Polochic fault of the Swan island, the depression of Honduras, the Guayape fault and even the Hess escarpment, even though this is submarine and therefore not contemplated in the morphotectonic analysis of the continental topography. The western and central areas of the Chortís block indicate a lot of similarities, which in turn will be interesting to study their small differences in order to arrive to conclusions about their block differences.

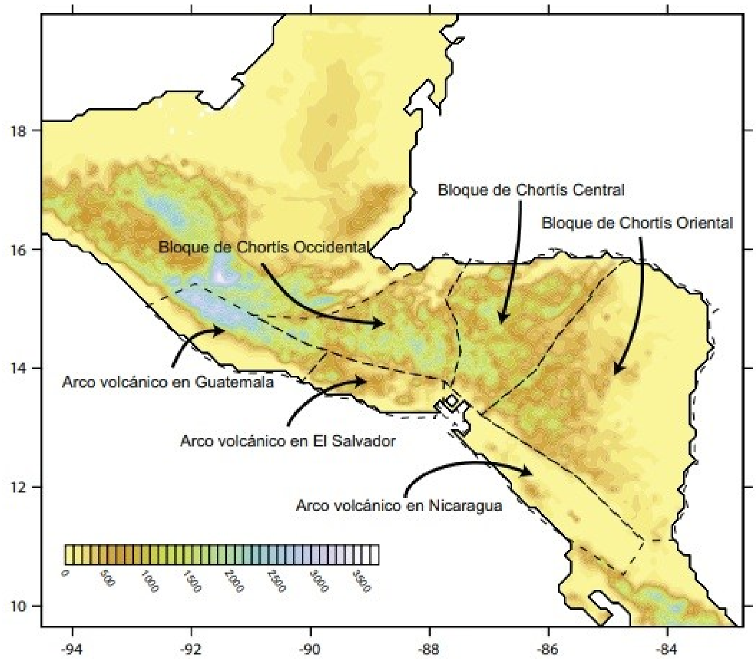


Figure 2: Morphotectonic zone of the study area over the smoothed digitalized model cells of 10 km side. (Alvarez J, 2006)

Western area of the Chortis block.

It extends from the boundary of the North American and Caribbean plates, in the Motagua fault zone to the Honduran depression, including the one made up of graben and the abundance of this in the area. To the south the area is limited by the volcanic arc, and its western extreme to Guatemala and the rest to El Salvador. We can make a difference inside this western area of the Chortís block in at least two parts. One of them in which the height, in a minor extent, is less than 25% of the quartile in the southern part, and in greater height, beyond the 75% quartile. The graben of Sula is located inside the northern sector, clearly marked by the 80 meters above sea level curve, and corresponds to the minimum height curve. This minimum represents the lowest part of the slope that boundaries with the sedimentary basin of the Sula graben. If we follow this basin to the south we find a system of grabens, with two mayor ones located in parallel, and continuing to the southeastern extreme linking to the Fonseca gulf. This discontinuous depression is what has come to be called “Honduran Depression” (Muelhberger 1976). The boundary between the northern and southern of this area is fuzzy, but it is build up by a series of faults in an EW direction and its print on the topography stands out and marks one the principal families in the direction rocks and polar graphics, in the case of facial orientation they correspond to the family orientation heading north, which indicates that this is the direction of the principal dip.

Jointly to N-S direction and the facial orientations we can find a N80°E±20° one, which corresponds to a N170°E±20° fractured family, and another less important N120°E and N290°E which would correspond to the direction fracture N20-30°E; these directions represent the normal faults that boundary the grabens. If we observe the drainage net we find these three clear directions represented. We observe in the drainage net as the E-O directions are frequent especially in the medial area, the NO-SE directions abound in the southern part and the NE-SO is divided into two families, one of them, more northern, abound in the north, in the graben of Sula environment, and the other one especially in the surroundings of Motagua and Jocotán faults, which have this direction.

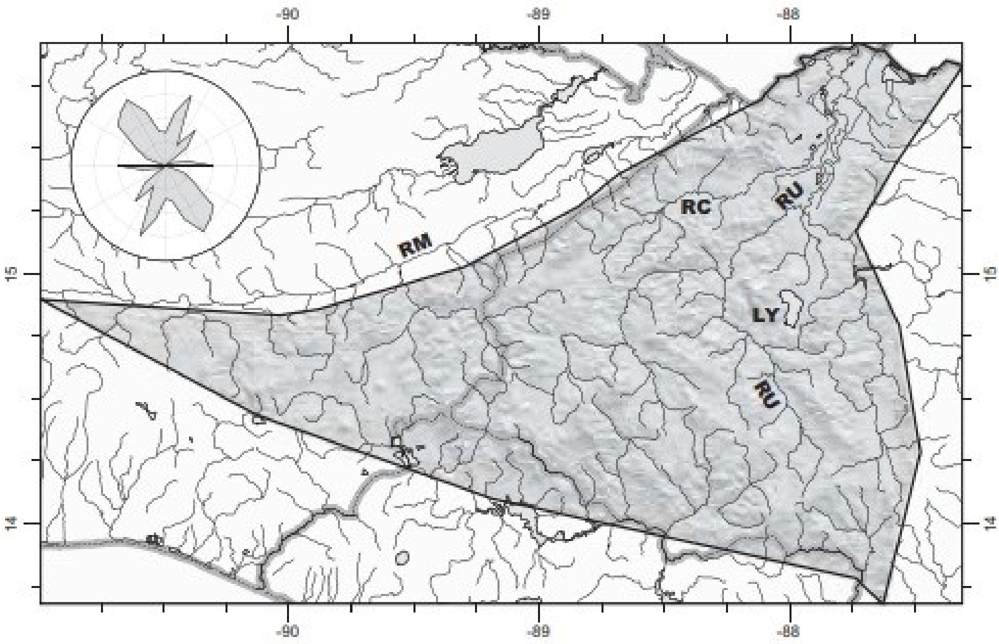


Figure 3: Principal drainage net in the western area of the Chortís block and directions path. RM: Motagua river; RC: Chamelecón river; RU: Ulúa river; LY: Yojoa lake. (Alvarez J, 2006)

This area traditionally is defined as “Honduran N-S direction graben zone”, but nevertheless, as you can observe in figure 4, the grabens don`t have any N-S direction, instead in the southern part they have a NNO-SSE direction and in the northern part a NNESSO direction. This block structuration, horst and graben type, is clear in the southern part, were at least 6 structures of horst can be counted. The biggest graben of the southern part is located in the western extreme, the Ipala graben (GI in Figure 4), which stands for abundant volcanism. This graben is limited to the north by the Motagua-Jocotán fault system, and in the south it blurs into the volcanic arc of El Salvador, in between the Guatemalan arc (to the west) to the El Salvador arc (to the east) exactly. The Ipala graben is the last one that makes its way into the west of the great grabens of Honduras, being the more extended and depressed of the southern part, only the Sula great graben in the north is bigger.

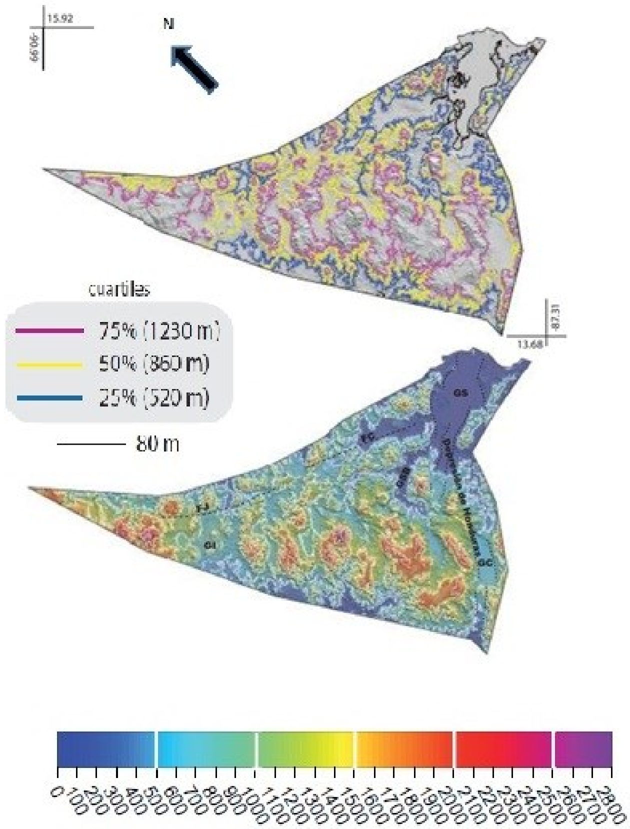


Figure 4: Morphometric zone of the western Chortís block. Upper part – Curve contour that corresponds to the digital elevation model quartiles. The black line represents the 80 above sea level curve, which marks a minimum in the curve of the hipsogram of figure 4. Lower part: Morphometric map. The contour lines have an interval of 500 meters. FJ: Jocotán fault; FC: Chamelecón fault; GI: Ipala Graben; GSB: Santa Bárbara graben; GS: Sula graben; GC: Comayagüa graben. (Alvarez J, 2006)

Similar to the western zone, this central zone can be divided in two parts. The northern part characterize by a series of graben and big structures in E-W to NE-SW, like the Aguán Valley, which forms a series of extended valleys that end up in the Caribbean Sea. The valley which is furthest east has a more northern direction and it is also the northern limit of the Guayape fault, which in turns extends with a SW direction to the Fonseca Gulf, giving way to a series of elongated vallyes in a NE-SW direction.

2. GEOCHEMICAL RESULTS

In the geological map describe in figure 5, details the zonification of the study systems, distributed in the country. In the Northern part 4 tectonic systems were analyzed which are divided into North Central, North 1, North 2 and North 3; and in the south one subductive system with volcanic influence.

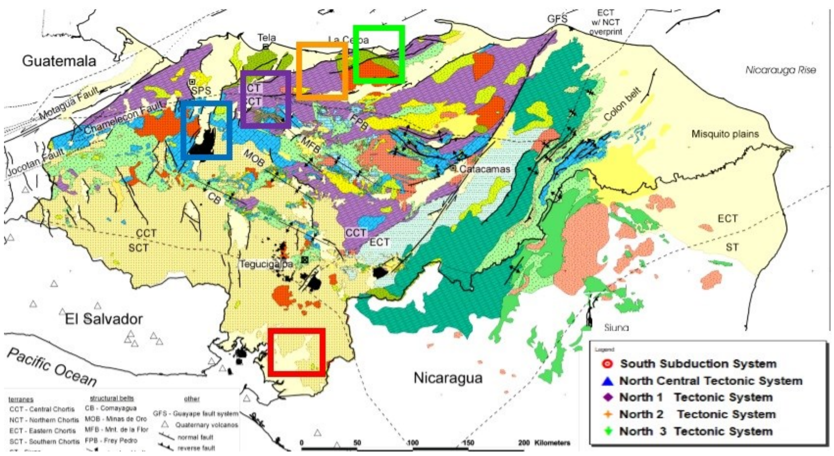


Figure 5: This geological map shows the system zonification: subductive and tectonic based on the related geological influence structures.

The isotopic analyses of water samples from geothermal manifestations and give information on the origin of the field discharges, on their age, on possible underground mixing between different waters, on water-rock interaction, and on steam separation processes. Both systems describe evaporation (North Central and subductive) by exchanges with the rock and the isotope diagrams shows that the North Central system suffers more evaporation in contact with the rock.

The North 1, North2 and North 3 Tectonic systems have suffer exchange with H_2S without evaporation and probably influenced by fresh waters of an aquifer and that is the reason why it is located above the World Meteoric Line.

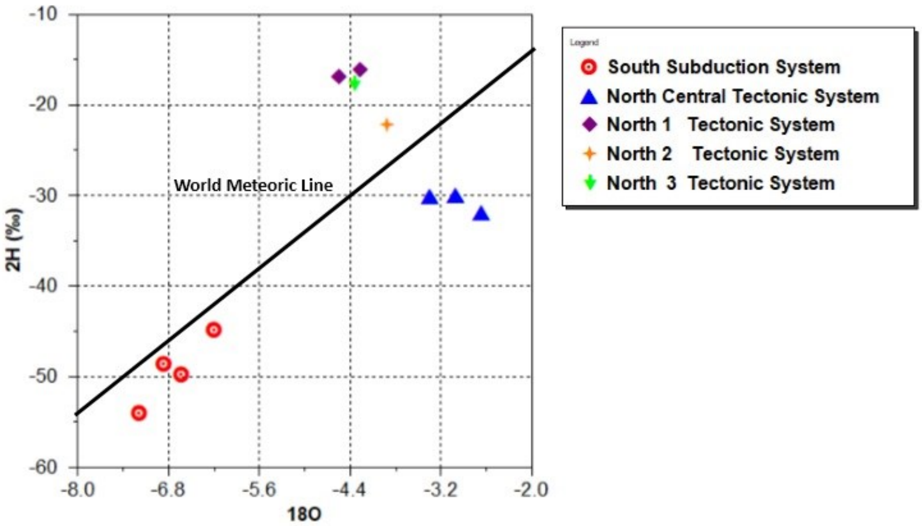


Figure 6: Diagram di variant, deuterium and oxygen 18 stable isotope, with world meteoric baseline

In the following tables, the analized geothermal water and its physical and chemical variables are shown, and it is important to point out that the low subductive systems are included in order to have a comparison effect. The variables shown are a product of a series of field studies and lab analysis. The values represent the anual average of each of the variables taken in the field and rectify in the lab. The laboratory which made the analysis was the one belonging to the National Electric Company (ENEE), located in Tegucigalpa, Honduras, following the propose geochemical exploration methology for this type of trials. (Arnonsson S., Fournier, Giggenbach)

The composition of geothennal fluids depends on many factors. The most important are temperature dependent reactions between host rock and water. Leaching plays an important role when the amount of a particular constituent is too small to attain equilibrium. However, processes of mixing, boiling and cooling usually have a significant influence on the final composition of the geothermal water.

Table 1: Classification and nomenclature of the system, coordinates, pH, superficial manifestation of the liquid phase, conductivity and the dissolved solids total.

Site	Location	North	East	pH	T °C	Conduct us/cm	TDS ppm
La Barca	North Central Tectonic System	397805	1670588	8.36	76.5	2510	1654.09
El Olivar 1	North Central Tectonic System	405811	1672675	8.36	72.9	2240	1476.16
El Olivar 2	North Central Tectonic System	406147	1673285	8.15	59.7	2360	1555.24
Namasigue	South Subduction System	486311	1440362	8.19	76.5	1323	871.857
El Estribo	South Subduction System	499413	1441022	8.74	80.6	972	640.548
Mordica	South Subduction System	503606	1496195	8.08	82	2470	1627.73
Pavana	South Subduction System	503643	1496423	7.84	70	929	612.211
El Oro-Agua Caliente	North 1 Tectonic System	481116	1724972	8.78	80.4	431	284.029
Agua Caliente	North 1 Tectonic System	481878	1725060	8.72	79.3	385	253.715
Los Hervederos	North 2 Tectonic System	490511	1727290	7.61	93.3	765	504.135
Jutiapa	North 3 Tectonic System	549636	1741616	8.47	86.7	613	403.967

Table 2: Cations concentration in each of the systems.

Site	Location	Li ppm	Na ppm	Mg ppm	K ppm	Ca ppm
La Barca	North Central Tectonic System	1.16	565.86	3.87	38.5	31.35
El Olivar 1	North Central Tectonic System	1.21	469.32	9.3	40.47	44.31
El Olivar 2	North Central Tectonic System	1.23	504.7	7.62	41.85	43.88
Namasigue	South Subduction System	0.29	344.81	0.12	8.18	64.69
El Estribo	South Subduction System	0.13	162.05	0	4.55	26.47
Morolica	South Subduction System	0.89	422.34	0.59	16.81	41.94
Pavana	South Subduction System	0.22	217.83	0.14	8.31	25.4
El Oro-Agua Caliente	North 1 Tectonic System	0.66	84.05	0.01	2.84	2.19
Agua Caliente	North 1 Tectonic System	0.51	75.04	0	2.55	1.48
Los Hervederos	North 2 Tectonic System	0.34	125.3	0.07	6.74	21.56
Jutiapa	North 3 Tectonic System	0.26	119.28	0.02	4.68	3.49

Table 3: Anions concentration in each of the systems.

Site	Location	NH4 ppm	Cl ppm	F ppm	SO4 ppm	NO3 ppm	HCO3 ppm
La Barca	North Central Tectonic System	1.5	116.1	8.0	175.0	0.0	1092.1
El Olivar 1	North Central Tectonic System	1.6	96.8	6.8	120.0	0.0	1058.2
El Olivar 2	North Central Tectonic System	1.6	100.8	7.0	85.0	0.0	1307.1
Namasigue	South Subduction System	0.0	495.9	1.0	225.0	0.0	14.0
El Estribo	South Subduction System	0.0	35.6	1.7	345.0	0.0	13.5
Morolica	South Subduction System	0.0	80.8	5.9	850.0	0.0	208.2
Pavana	South Subduction System	0.0	54.0	3.3	342.0	0.0	54.3
El Oro-Agua Caliente	North 1 Tectonic System	0.1	6.4	3.2	60.0	0.0	85.0
Agua Caliente	North 1 Tectonic System	0.2	6.4	2.6	56.0	0.0	82.0
Los Hervederos	North 2 Tectonic System	0.1	43.2	4.5	185.0	0.0	51.4
Jutiapa	North 3 Tectonic System	0.2	34.8	2.9	100.0	0.1	77.5

Table 4: Neutral compound concentration in each of the systems.

Site	Location	H2S ug/l	SIO2 ppm	Co2 ppm
La Barca	North Central Tectonic System	0.0	107.6	795.1
El Olivar 1	North Central Tectonic System	61.0	115.4	769.4
El Olivar 2	North Central Tectonic System	0.0	116.8	951.4
Namasigue	South Subduction System	82.0	63.7	11.22
El Estribo	South Subduction System	38.0	66.9	11.6
Morolica	South Subduction System	97.0	139.77	150.1
Pavana	South Subduction System	0.0	105	46.9
El Oro-Agua Caliente	North 1 Tectonic System	784.0	71.1	89.1
Agua Caliente	North 1 Tectonic System	735.0	66	74.4
Los Hervederos	North 2 Tectonic System	689.0	69.2	36.3
Jutiapa	North 3 Tectonic System	730.0	80.6	100.2

Table 5: Heavy metal concentration calculation.

Site	Location	Fe ppm	Al ppm
La Barca	North Central Tectonic System	0.106	0.18
El Olivar 1	North Central Tectonic System	0.208	0.19
El Olivar 2	North Central Tectonic System	0.19	0.17
Namasigue	South Subduction System	0.2200	0.2500
El Estribo	South Subduction System	0.1800	0.17
Morolica	South Subduction System	0.3500	1.51
Pavana	South Subduction System	0.4500	0.28
El Oro-Agua Caliente	North 1 Tectonic System	0.114	0.25
Agua Caliente	North 1 Tectonic System	0.145	0.22
Los Hervederos	North 2 Tectonic System	0.919	0.65
Jutiapa	North 3 Tectonic System	0.095	0.21

Table 6: Stable isotopes concentration calculation.

Site	Location	18O	2H
La Barca	North Central Tectonic System	-2.66	-32.07
El Olivar 1	North Central Tectonic System	-3	-30.04
El Olivar 2	North Central Tectonic System	-3.35	-30.23
Namasigue	South Subduction System	-6.2	-44.98
El Estribo	South Subduction System	-6.63	-49.84
Morolica	South Subduction System	-7.19	-54.1
Pavana	South Subduction System	-6.86	-48.73
El Oro-Agua Caliente	North 1 Tectonic System	-4.28	-16
Agua Caliente	North 1 Tectonic System	-4.55	-17.05
Los Hervederos	North 2 Tectonic System	-3.91	-22.31
Jutiapa	North 3 Tectonic System	-4.34	-17.82

When cations and anions are separated in a graph, we can see a clear difference between each of these systems. Figure 7, shows that these are different reservoirs for each system. There is a reservoir in the northern zone that coincides with the chemistry of the southern system.

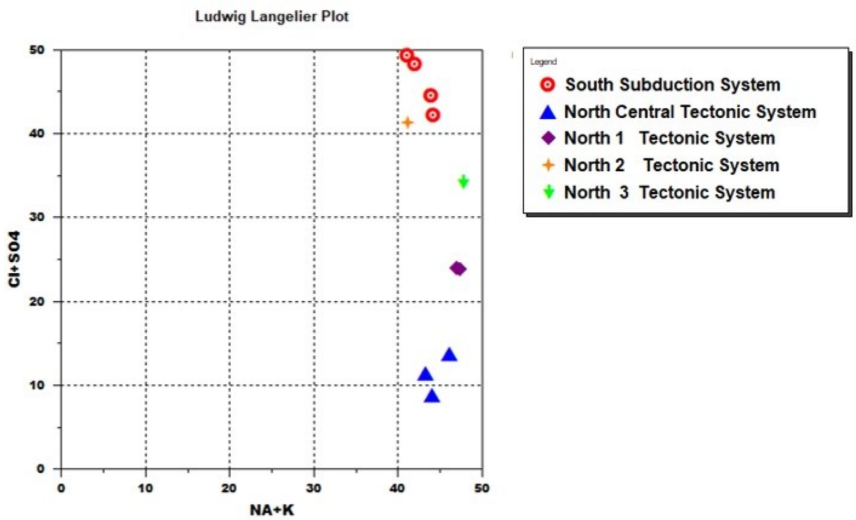


Figure 7: Rectangular diagram Na-K Vs Cl-SO4

In the Piper diagram, figure 8, details the chemical composition of the different waters in study. Just as the graphics shows we have 5 types of water which clearly describe our system.

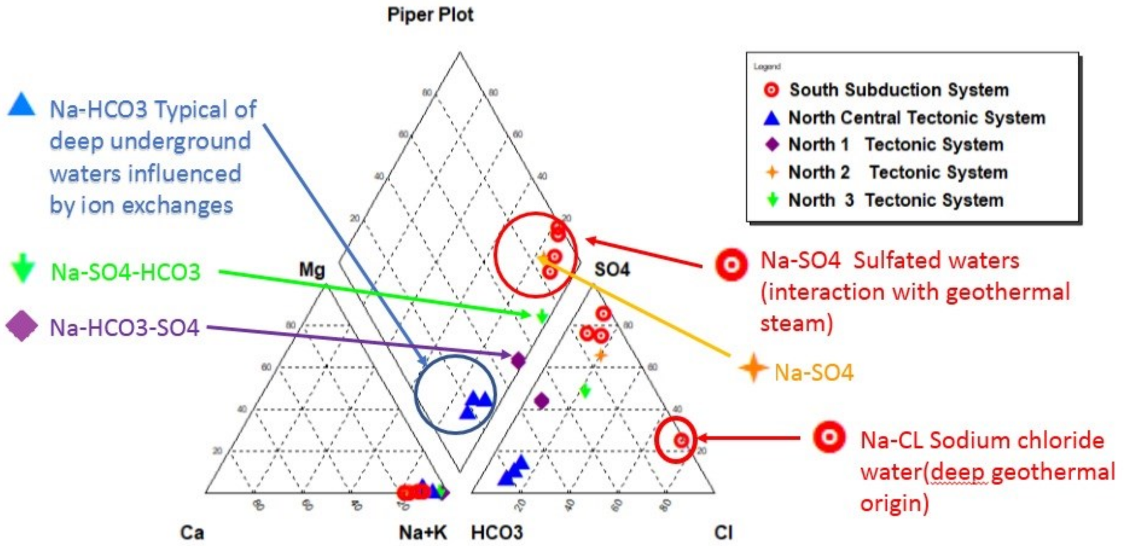


Figure 8: Pipper triangular diagram, geochemical classification of the systems.

In figure 9, shows the sulfated waters for the subductive system and bicarbonated waters of the tectonic system. Higher content of chlorides are observed in one site of the subductive system.

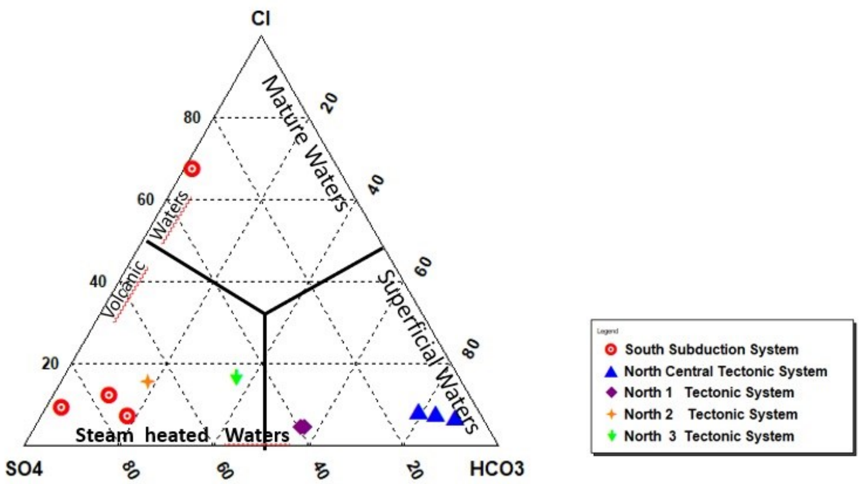
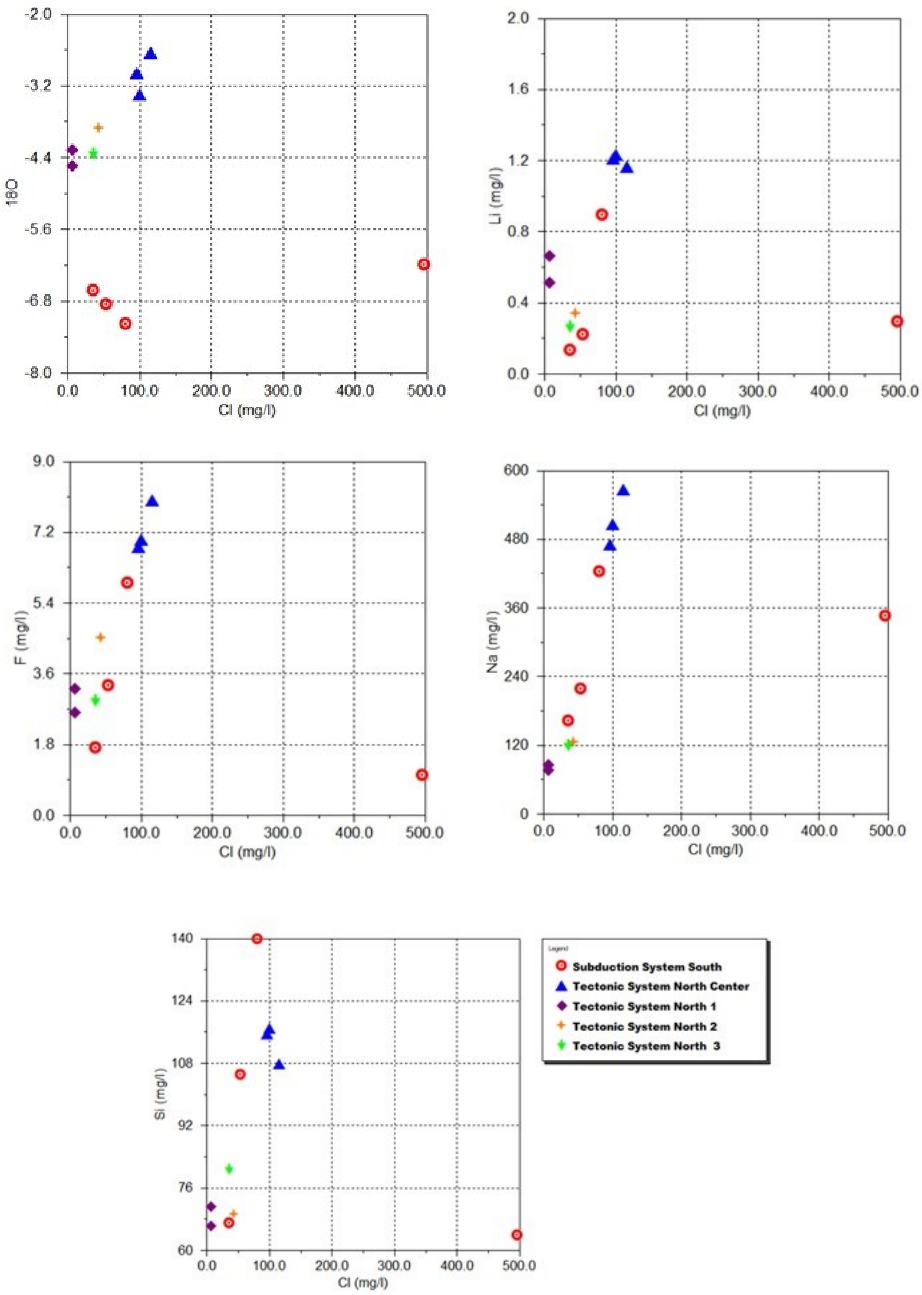


Figure 9: Ternary diagram

The square graphs indicate that there are some differences between the linear relationships of Cl with other constituents in the altered sites. These indicate a strong mixture in waters of some aquifer that ascend to the surface.



Just as describe in figure 10, (The Giggenbach triangle), the north central tectonic system is composed of immature waters and thus the cationic geothermometers **cannot be applied**. In case of other systems, they are partially in equilibrium. We can apply the technique of cationic geothermometers but only to compare with the rest of geothermometers and with the specific models in equilibrium which are the ones that give the real temperatures of the reservoir, according to Giggenbach in the case of reservoirs located in the subductive system; the temperatures are between the 120 to 140 degrees Celsius and for the north central tectonic systems the temperatures should range between the 90 to 120 degrees Celsius. Thus, the information just mentioned applied to the most representative reservoirs in each of the systems.

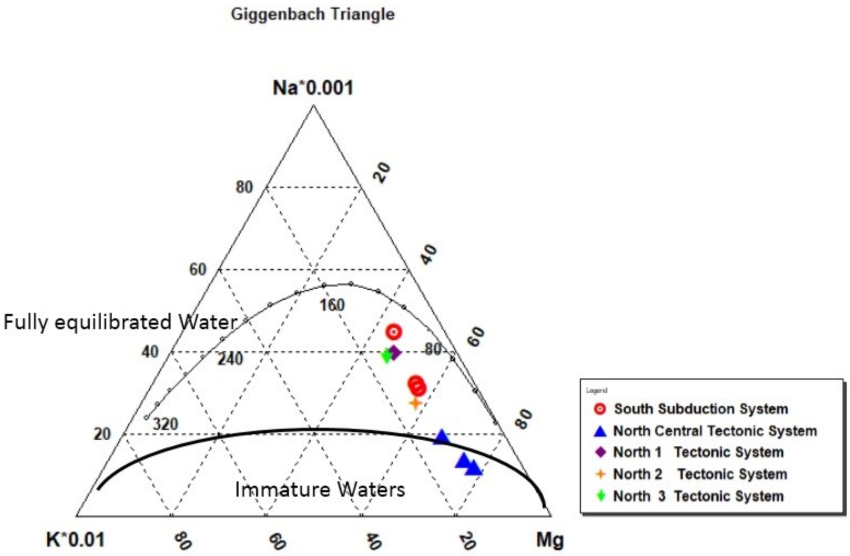


Figure 10: Giggenbach Triangle Diagram

In figure 11, describes the geothermometry of quartz Fournier 1977, quartz Arnorsson 1985 Fournier Potter 1982 and Chalcedony Fournier 1977; applied for alkaline metals. The range of temperature for subductive systems is between 110 to 150 degrees Celsius and for the North Central Tectonic System around 110 to 145 degrees Celsius.

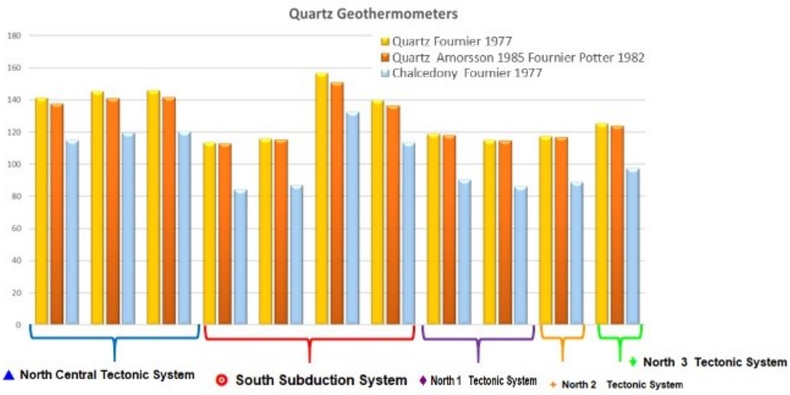


Figure 11: Quartz Geothermometers

In figure 12, the water in many of the hot springs consists of mixtures of deep hot water and shallow cold water. Truesdell and Foumier (1977) have proposed a plot of dissolved silica versus enthalpy of the hot spring water to estimate the temperature of the deep hot water component.

It was necessary to introduce the mixing modeling technique that what it does is to find the temperature in the equilibrium of a particular species before the thermal water is altered by the influence of fresh water inside the subsoil. And this is done by saturation curves of one species were the enthalpy between these two water mixtures is sought and upon reaching the saturation curve, the temperature at which the mixture occurred can be identified. And this is more precise temperature in the Reservoir.

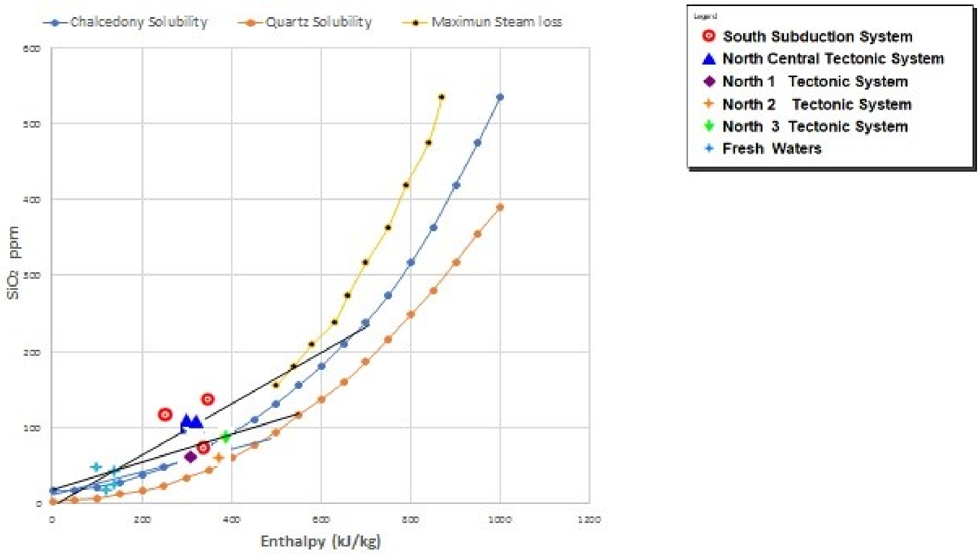


Figure 12: Silica-enthalpy mixing model

In figure 13, Foumier (1977) suggested the use of an enthalpy-chloride diagram to predict underground temperature. This mixing model takes into account both mixing and boiling processes. Its application basically involves relating analyzed chloride levels to water enthalpy which can be derived from measured discharge temperature, geothermometry temperature, and silica-enthalpy mixing model temperature.

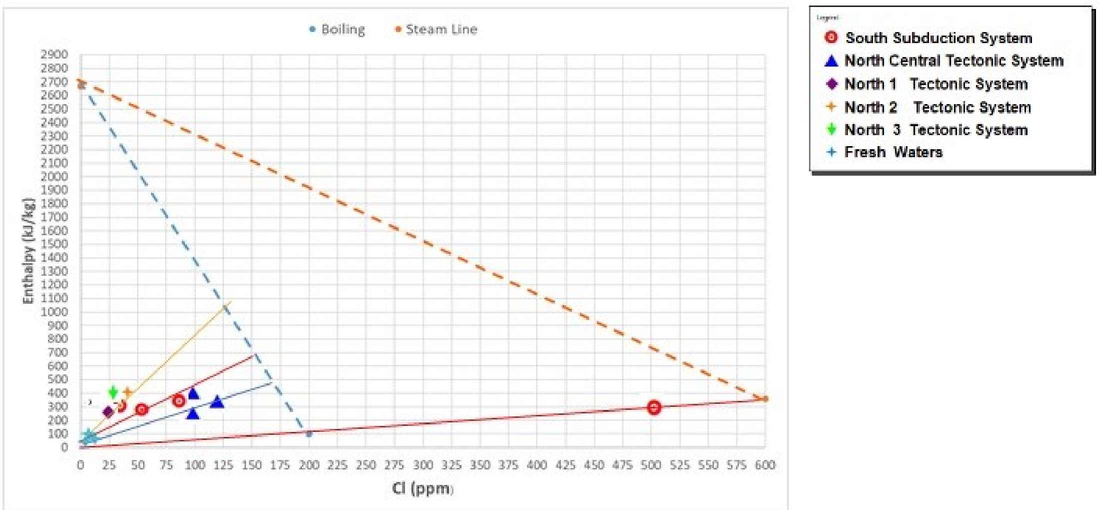


Figure 13: Enthalpy-chloride mixing model

CONCLUSIONS

1. Northern and Central geothermal System are directly related and above in the tectonic faults.

2. In the country it exists different chemical classification of water and thus presenting a very diverse resource; permitting the possibility of exploitation for direct use and/or generation of electricity of low enthalpy. The distribution of our systems covers great part of the Honduran territory, and it is worth mentioning that all the sites study and analyzed in this paper have not been granted exclusive licensing by the government nor studied before, hence giving way for future investigations in these areas.

3. The geothermometry of the waters we can conclude that:
   A. The subductive system has a range of temperature between 140-177 °C
   B. The North Central tectonic system has a range of temperature between 120-165 °C
   C. The North 1 tectonic system has a range of temperature between 130-158 °C
   D. The North 2 tectonic system has a range of temperature between 130-185 °C
   E. The North 3 tectonic system has a range of temperature between 120-167 °C

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