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Exploration in the Subductive Influence Zone Honduras

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ABSTRACT

The conditions in Honduras are very different from the rest of Central American countries due to the lack of active volcanos. The heat source related to the geothermal systems in Honduras comes from active or direct tectonism, hence the conversion and interaction of three tectonic plates. In the north and west of the territory, a transforming geological fault system related to the North American and Caribbean Plate. This represents the biggest signs of activity because they come along with mountain chains who maintain a subterranean water recharge and is heated from shallow reservoirs due to a natural thermic gradient. In the central part of the territory, we can also find the same fault pattern, known as Polochic-Motagua-Chamelecón. In the southern part of the country or the pacific, there is an influence of the Cocos Plate with the Caribbean Plate considering closeness of the subduction process. This last one presents physiochemical manifestations very different from the rest of the country. This document reflects the exploration investigation that been held by the Honduran government in the southern territory, where we find superficial manifestations: heated mud, smoky soil, hot springs and some fumarole. This last manifestation is more notable during the rainy season. It is also important to mention the proximity to the Cosigüina Volcano, which is located in the neighboring country of Nicaragua.

1. INTRODUCTION

Honduras presents a slow development concerning the geothermic exploration, compared with other Central American countries. Featuring manifestations like boiling mud pots, steaming ground, boiling springs and fumaroles occur with less intensity then in the other Central American countries. In the area of interest of Namasigüe in South Honduras, studies are aiming to characterize hydrothermal manifestations, evidenced through superficial waters up to 80 degrees and wells, drilled mainly in the search of drinking water. For the time being, the local community does not consider the energy potential of these resources. The ongoing investigations are aiming to the characterization of the hydrothermal resource in Namasigüe in order to support decision taking regarding the development of a geothermal project in the area.

The ongoing studies take into account the distance to the possibly influencing subduction zone along the Gulf of Fonseca (Figure 1), the volcanic active area in Nicaragua with nearby Consigüina volcano (William and McBirney, 1969) and the tectonic structures that facilitate the deep circulation of meteoric waters (Hahne/ Ermertz 2019 after Eppler et al. 1986; Heiken et al. 1991), which cause the main geothermal potential in Honduras.

The objective of the present document is to verify and further develop findings of former exploration campaigns taken out by ENEE, which by geochemistry show different hydrochemical character of the Namasigüe manifestations in comparison to other superficial manifestations of the country. The results of the ongoing recognition phase for the Namasigüe geothermal area includes chemical analysis of the hydrothermal waters in the area, taken out by ENEE as well as the results of a remote sensing study regarding structural geology, taken out by the Institute for Geosciences and Natural Resources (BGR) from Germany in 2019. The results of these studies were supported by the regional German Technical Cooperation Project "Identification of Geothermal Resources in Centralamerica", implemented by BGR with the Central American Integration System SICA.

In Figure 1, areas in red and purple correspond to Namasigüe and El Triunfo communities where the conglomerate of hydrothermal manifestations, described in this document, is located. These two communities belong to the southern department of Choluteca in Honduras. Namasigüe in the west covers 217 km^2 and El Triunfo in the east covers 307 km^2. Figure 2 visualizes the geology of the tectonic plates and the subduction zone, where the Cocos Oceanic plate subducts under the continental Caribbean plate.

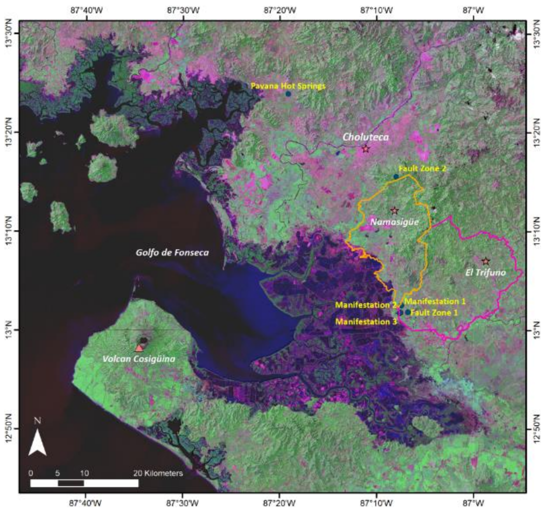

Figure 1: Area of Interest Namasigüe and El Triunfo (Lineament Mapping in Namasigüe/El Triunfo (Choluteca, Honduras) based on Remote Sensing data (Ermertz and Hahne 2019).

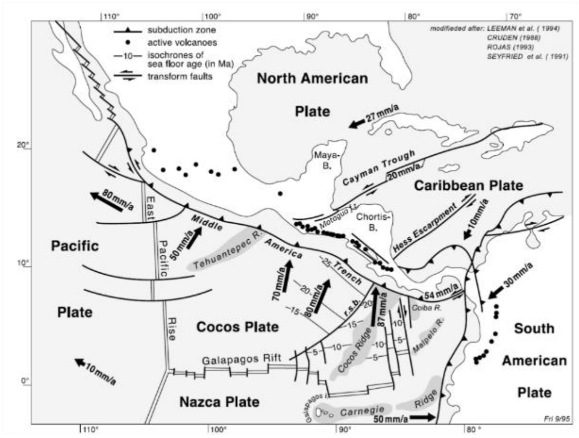

Figure 2: Regional tectonic setting of Central America (Ermertz and Hahne 2019, after Frischbutter 2002)

In this paper, ENEE presents the new findings of the geochemical and structural geology studies in the area of interest in Choluteca department with the hydrothermal manifestations of Namasigüe and El Triunfo. The data will support the characterization of the present geothermal resources.

Based on the geological map of Honduras, the area of interest belongs to the Group of Quaternary alluvium or Quaternary volcanic rocks, which are major mafic in composition (William and Mc Birney, 1969; Anderson, 1985). These consist of lava flows and volcanic cones, andesitic basalts of olivine composition, pyroclastic debris and volcanic tuffs. Most of these rocks can be located extending from the eruptive Center of the Yojoa Lake to the Gulf of Fonseca. This area also coincides approximately with the depression of Honduras (Italo-Latin American Institute, current state and development of geothermal resources in Central America, 2010).

As Ermertz and Hahne (2019) describe in their report, "the Central American complex basically exists of Precambrian-Paleozoic continental terranes that accreted to form the Chortis block by Late Cretaceous times (Mann 2007; Rogers et al. 2007)". Striking perpendicular to the regional volcanic chain, Mann 2007 indicates, that these also might have been playing a role in the structural formation during the historical subduction process of the Cocos and Caribbean Plate. Besides the Guayape fault, which is the major linear feature of Honduras, the Motagua fault zone delimits the Chortis block to the north, reflecting the tectonic plate boundary between the Caribbean and the North American plate (James, 2007).

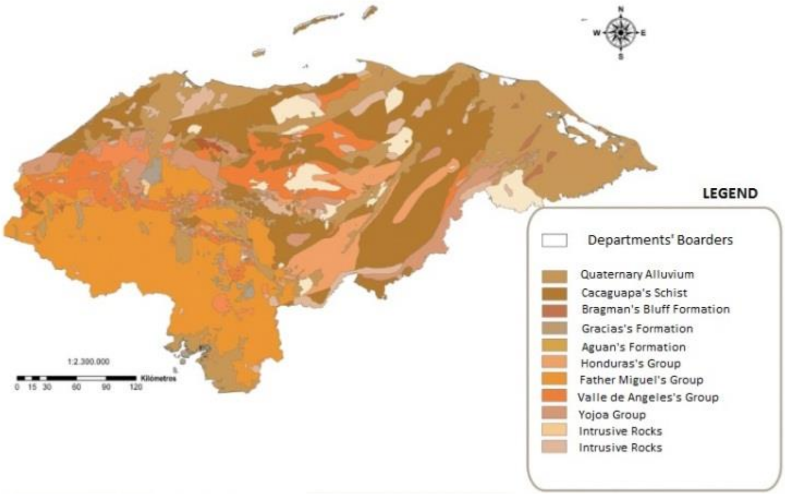

Figure 3: Geological map of Honduras (Ministry of Agricultural and Cattle Raising, SAG, 2009).

2. GEOTHERMAL DEVELOPMENT IN HONDURAS

At the present, Honduran authorities have been awarding concessions of five geothermal sites aiming to power generation (Platanares, San Ignacio, Sambo Creek, Pavana and Azacualpa). Only the site of Platanares has been developed so far, where since 2017 a binary power plant is installed and in commercial operation. The National Power Company ENEE currently makes exploration efforts at the geothermal sites of La Barca, El Olivar y Namasigüe, partially supported by the German Cooperation. The below shown Table 1 details the results obtained by the geothermometry and its respective geochemical classification.

Table 1: Geochemical classification of the geothermal systems of Honduras (ENEE, 2019).

GEOTERMIC SYSTEMS	TEMPERATURE (^{0}C)	GEOCHEMICAL CLASSIFICATION
PLATANARES	225	HCO_3-NA
SAN IGNACIO	190	HCO_3-NA
SAMBO CREEK	155	SO_4-NA
PAVANA	170	SO_4-NA
AZACUALPA	185	SO_4-NA
LA BARCA	185	HCO_3-NA
EL OLIVAR	170	HCO_3-NA
NAMASIGUE	185	CL-NA

Figure 4 illustrates sites under exploitation concession marked (left) in red, and sites which are currently under investigation in the National Electric Energy company ENEE marked in yellow (right).

Figure 4: Maps of geothermal areas of interest in Honduras (ENEE, 2019).

3. METHODOLOGY FOR STRUCTURAL GEOLOGY (REMOTE SENSING DATA)

The Federal Institute for Geosciences and Natural Resources BGR used remote sensing data and overview field data in Quantum GIS (version 3.4.4) for further analysis and lineament vectorization (Ermertz and Hahne, 2019):

- Enhanced and geocoded satellite images (using ENVI for e.g. high pass filtering, histogram stretching, shaded relief generation):
    - Sentinel 2a MSI acquired November, 13, 2018; used multispectral bands with 20 m ground resolution.
    - RapidEye for Namasigüe; 5 m ground resolution.
    - SRTM 30 m digital elevation model.

- Information from overview-field work of 4 days:
  - Shape and visibility of lineaments.
  - Additional geological and tectonic information.
  - Field photos.
  - Waypoints (WP) GPS measurements of findings and locations of photos.

The spatial reference system used for this study is UTM 16 N, WGS 84. Based on the Lineament Mapping Report from Ermertz and Hahne 2019, different thematic layers were created:

- Shaded relief maps
- Enhanced Sentinel 2a multispectral images
- Waypoints with corresponding data tables concerning information from fieldwork (manifestations, lithology, photos etc.)
- Faults, large-scale
- Faults, small-scale
- Exploration area

Besides, secondary data regarding the major fault systems of the northern Chortis block and the location of the study area have been considered and following Ermertz and Hahne 2019, the structures dominantly strike N60°W, corresponding to the Nicaraguan depression (13), N30-35°E corresponding to the Guayape fault system and N-S corresponding a series of graben systems (5,8,9).

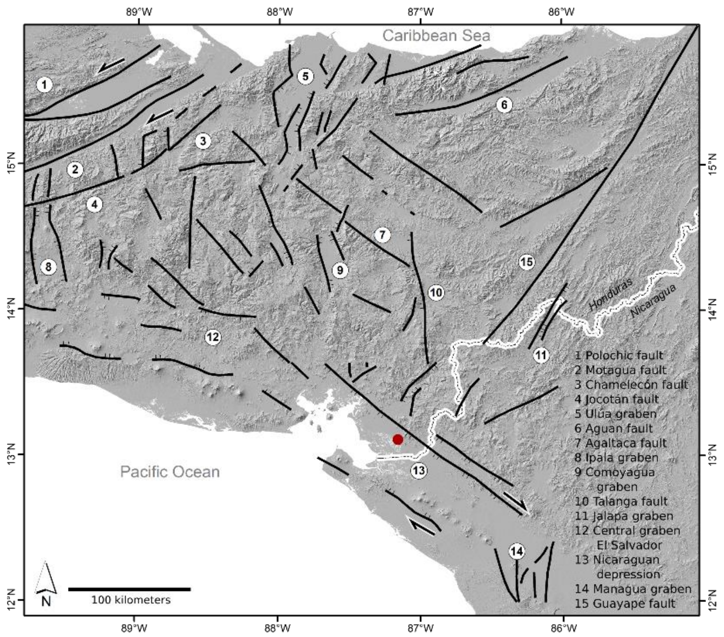

Figure 5: Major fault systems of the northern Chortis block and the location of the study areas (indicated in red) (Ermertz and Hahne, 2019).

4. METHODOLOGY FOR GEOCHEMISTRY

The display of results in the present chapter refer to hydrochemical samples taken from hot springs in the area of interest.

The concentrations of the cations sodium, potassium, calcium, magnesium, silica, and lithium and the anions bicarbonate, chloride, sulphate, nitrate and fluoride, were analysed. The water types were classified based on piper and the program Aquachem® was used for the graphical representation of the analyses. Subsurface temperatures were calculated using the quartz geothermometer of Fournier and Potter (1982), the sodium-potassium-calcium geothermometers of Fournier and Truesdell, (1973) and Arnorsson (1989) and the sodium-potassium-magnesium geothermometers of Giggenbach (1988).

Spectrophotometer, atomic absorption, mass spectrograph, potentiometer, spectrophotometer Ultraviolet/Visible, pH meter, Conductivity, were methods used in this analysis. Based on the testing of the ionic balance and following the lab method as stipulated for this analysis, which is detailed in Table 2, the data is presented through triangular diagrams of Piper and polygonal Stiff diagrams, applied to the examination of the geochemical results. The Piper diagram relates the concentrations of cations in a first triangle and the concentration of anions in a second triangle.

Table 2: Variables found, methods and equipment used. Summary table (Gems water, IAEA, 2004; Laboratory of ENEE, 2016).

MEASUREMENT VARIABLES	METHOD OF ANALYSIS	TEAM	BRAND	MODEL
TEMPERATURE	Direct measurement in field	Thermometer	VWR	
pH	Direct measurement in field and laboratory	pH meter	HACH	MM - 150
CONDUCTIVITY SPECIFIES	Direct measurement in field and laboratory	conductivity meter	WTW	197-I
NA +, K +, Ca 2 +, Mg 2 +, Li +	Atomic absorption flame air - acetylene and nitrous oxide - acetylene	Atomic Absorption Spectrophotometer	VARIAN	AA-240
Chloride (C1-)	Titration with silver nitrate	Volumetry		
Sulphates (S04 2)-	4 Sulfaver /HACH	UV-visible spectrometer	HACH	DR-2400
Bicarbonate (HC03)-	Titration by recoil with hydrochloric acid, sodium hydroxide and nitrogen gas	pH meter/volume	ORION	410A
Carbonates (C03)	Titration by recoil with hydrochloric acid, sodium hydroxide and nitrogen gas	pH meter/volume	ORION	411a
Carbon dioxide (C02)	Titration by recoil with hydrochloric acid, sodium hydroxide and nitrogen gas	pH meter/volume	ORION	412a
Total alkalinity	Sum of HC03 and C03			
Fluorides (F)-	Fluoride selective electrode	Selective electrode	OMEGA	PHB-23
Nitrogeno-nitratos (N-N03)	Reduction of cadmium	UV-visible spectrometer	HACH	DR-2800
Ammonia nitrogen (NH3-N)	Salicylate	UV-visible spectrometer	HACH	DR-2800
Hydrogen sulfide (H2S)	Methylene blue	UV-visible spectrometer	HACH	DR-2800
Silicon dioxide (Si02)	Silica molybdate	UV-visible spectrometer	HACH	DR-2800
ΔD o/oo yδ 180 o/oo	Laser technology	Equipment laser for isotope	losgatos	Generation 2

5. ANALYSIS OF RESULTS OF THE INFLUENCE AREA (STRUCTURAL GEOLOGY)

BGR conducted the structural analysis based on enhanced multispectral satellite images and shaded relief DEMs with different illumination angles, which enabled the detection of lineaments even in areas of low topography.

The remote sensing data visualises also major fault directions (NW-SE; N-S; NE-SW), especially in a regional scale (Figure 6) and shear lenses, represented mainly along NE-oriented transtensional faults (Figures 7 and 8) and probably resulting from the transtensional north-eastern movement of the Chortis Block according to the Guayape fault system (Figure 5). Most of the identified transtensional faults within the working areas show a right lateral sense of shearing (Ermertz and Hahne, 2019).

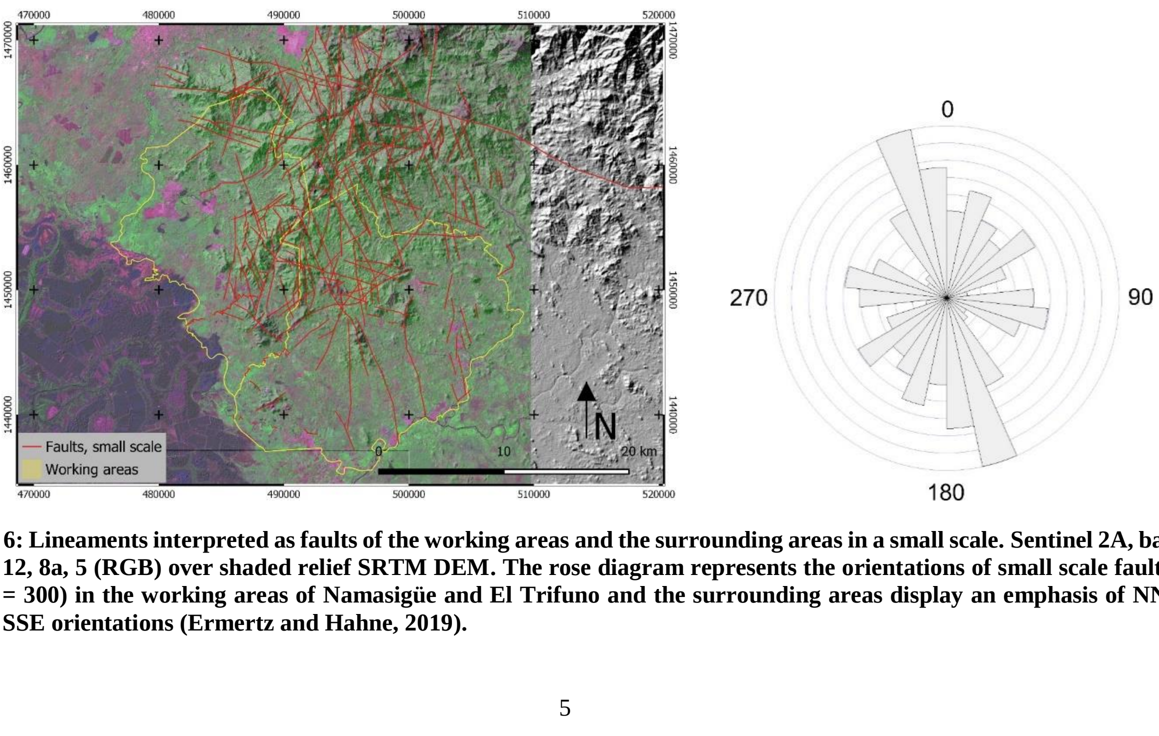

Figure 6: Lineaments interpreted as faults of the working areas and the surrounding areas in a small scale. Sentinel 2A, bands 12, 8a, 5 (RGB) over shaded relief SRTM DEM. The rose diagram represents the orientations of small scale faults (n = 300) in the working areas of Namasigüe and El Trifuno and the surrounding areas display an emphasis of NNW-SSE orientations (Ermertz and Hahne, 2019).

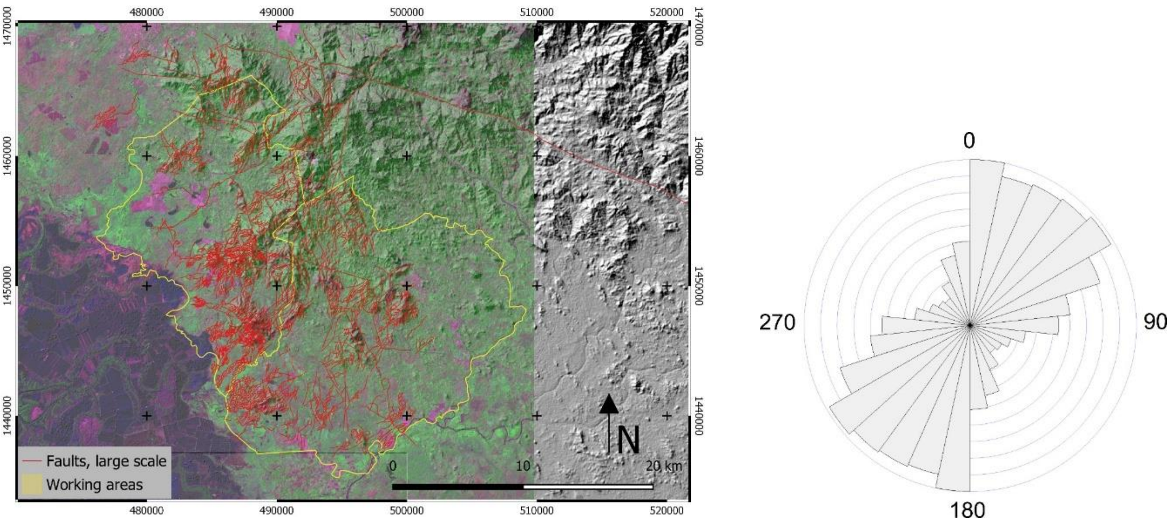

Figure 7: Large scale faults including the finer faults of shear lenses, of the working areas and the surrounding areas. Sentinel 2A, bands 12, 8a, 5 (RGB) over shaded relief SRTM DEM. The rose diagram represents orientations of large scale faults including the faults of shear lenses (n = 2216) in the working areas of Namasigüe and El Trifuno and the direct vicinity. The active NE-directed movement of the transtensional Guayape fault system becomes clear (Ermertz and Hahne, 2019).

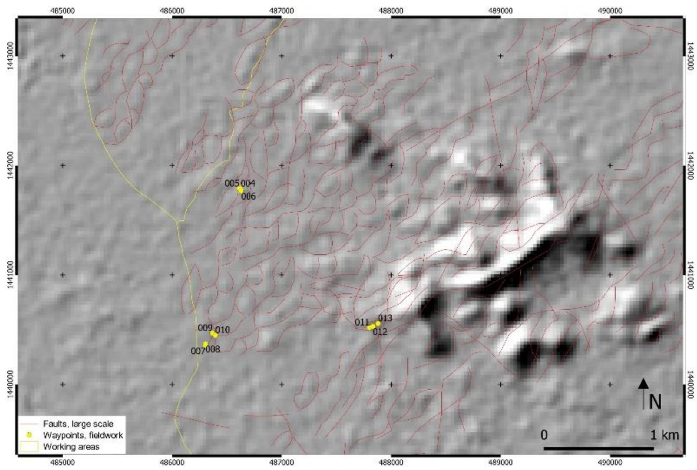

Figure 8: Shear lenses (delineated by fine lineaments, visible in a large scale) documented in outcrops of topographic high and low areas (Ermertz and Hahne, 2019).

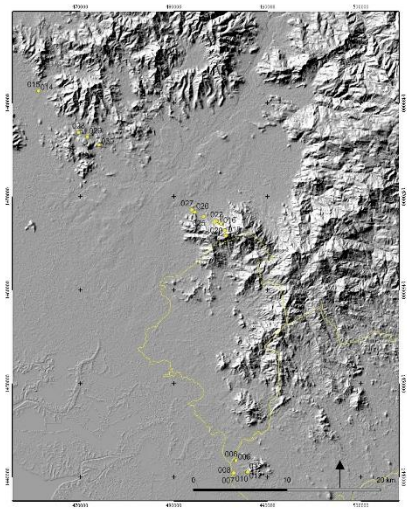

Figure 9: Waypoints of the field visits in the working area projected into SRTM shaded relief elevation model (Ermertz and Hahne, 2019).

6. ANALYSIS OF RESULTS OF THE INFLUENCE AREA (GEOCHEMISTRY)

Based on the geochemical analysis taken out in ENEE, the table and figures below detail representative and average data of previous campaigns and zonifications by consideration of the specific chemistry of each hot spring. Table 3 shows that the predominant anion is chloride, which is the typical representation of geothermal alterations in mature waters. This chloride concentration is not present in other Honduran sites, where the heat source is related to tectonic fault.

Table 3: Anion calculation (ENEE, 2016).

$N\text{-}NO_3$ mg/L	$N\text{-}NH_3$ mg/L	H2S µg/L	SO_4^{2-} mg/L	Cl^- mg/L	SiO2 mg/L	F- mg/L
ND	ND	82.00	225	**495.85**	63.70	1.03

Based on the results of cations visualized in Table 4, a high amount of sodium is found, which is a predominant characteristic of geothermal waters in the region. The low percentage of magnesium is a characteristic, which is present in every sample taken and analyzed in the subduction zone.

Table 4: Cations calculation (ENEE, 2016).

Na+ mg/L	K+ mg/L	Ca2+ mg/L	Mg2+ mg/L	Li mg/L
344.81	**8.18**	**64.69**	**0.12**	**0.29**

Furthermore, in Table 5, which is shown below, measured values for the bicarbonates, carbonates and carbonic anhydride are shown. HCO3 and CO3 values are necessary to obtain the ionic balance, as its concentrations are representative for geothermal waters.

Table 5: Alkalinity (ENEE 2016).

HCO3	CO3	CO2
14.00	1.53	11.22

The triangular diagram of Piper shown below, relates the samples of the area of interest, and it is possible to observe the ionic composition in them. Using the results displayed in Figure 10 as a baseline, it is possible to make a chemical classification of the sampled hydrothermal manifestations. It is worth noting that this kind of classification has not been made before in the area of interest.

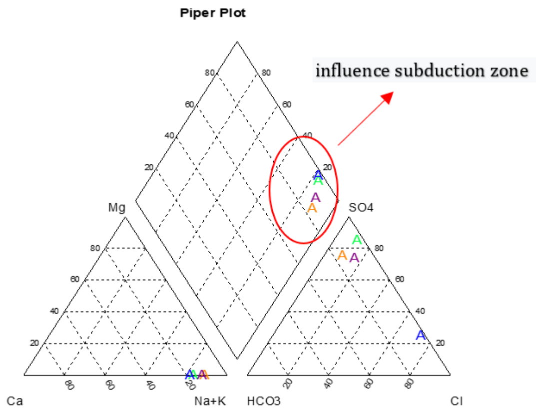

Figure 10: Triangular Piper diagram (ENEE, 2016).

Figure 11, shows an uprising in the parallel line of the anions, which indicates a high concentration of Cl-(Chlorides). As the uprising parallel line represents a high concentration of Na+ (Sodium), the sample can be considered a Chloride-Sodium sample type.

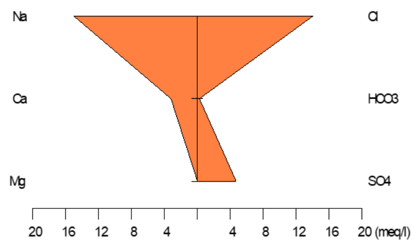

Figure 11: Stiff diagram (ENEE, 2016).

In Figure 12, the presence of predominant ion (Na) in every sample taken in the area of interest is noticeable, and also a relation to the isotope seems to be predominant (Deuterium).

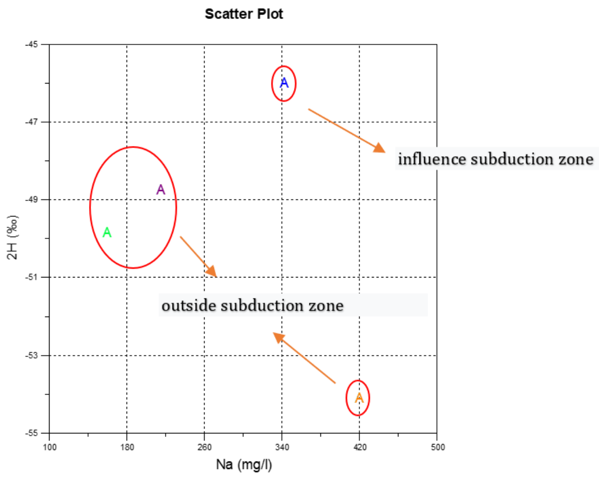

Figure 12: Square diagram Na- 2H (ENEE, 2016).

CONCLUSIONS

1. Honduras, even though does not have any active volcanism, does present geothermal conditions for the resource exploration.
2. The region along and influenced by the regional subduction zone of Honduras seems to differ from the in Honduras common fault structure dominated geothermal resources.
3. The differences lead a result that a geothermal system influenced by the subduction of plates gives a higher sustainability in the integration of variables in the conceptual model.
4. The findings lead to the estimation that the geothermal systems of southern Honduras might be a low and medium enthalpy resource.
5. Further detailed geological (structural) and broader geochemical campaigns are needed to be able to verify the current results.

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