Geochemical Exploration in Southern Honduras

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Geochemical Exploration in Southern Honduras

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ABSTRACT

This work presents geochemical data from a small area in southern Honduras. The results of the isotopic and geochemical analyses are used to characterize water types and geothermometers temperatures.

Four geothermal manifestations with temperatures higher than 60 °C were sampled. The analyses indicate the presence of both sodium-sulfate and sodium chloride waters.

New geochemical data from these four locations in southern Honduras are shown. Data are used to classify water types, to calculate reservoir temperatures and bring additional attention to geothermal development in Honduras, country where mid-temperature geothermal manifestations are present.

1. Introduction

Honduras presents a slow development concerning the geothermal exploration, compared with developments in other Central American countries. In the country exists manifestations like boiling mud pots, steaming ground, boiling springs and fumaroles; with less intensity than the rest of Central American countries. Also, it exists in the western and southern part of Honduras a more noticeable potential resource for the electrical energy generation than the rest of the country. These features occur in regions where Tertiary volcanism is present. However, the heat sources of these manifestations may be related either to extinct magmatic cameras or intrusive rocks. Figure 1 shows some superficial manifestations from hydrothermal water spring type. Fig. 2 shows a manifestation's temperature in a sample (82.2 ^{o}C, 179.96 ^{o}F).

Figure 1: Superficial manifestations from hydrothermal water spring type (zone #1, see fig. 4).

Figure 2: Manifestation's temperature in a sample. (82.2 ºC, 179.96 ºF), (zone #3, see fig. 4).

The soil characterization presented in Figure 3, specifically in the southern area of Honduras, corresponds to the formation known as *Father Miguel Group*. This is mainly composed by pyroclastic of fall and volcanic rock which extends from the south to the middle-east of the country. (William H. and McBirney R., 1969). A summary of Honduras´s Stratigraphy is shown in (Heiken et al, 1991). Below is shown the geological map of Honduras.

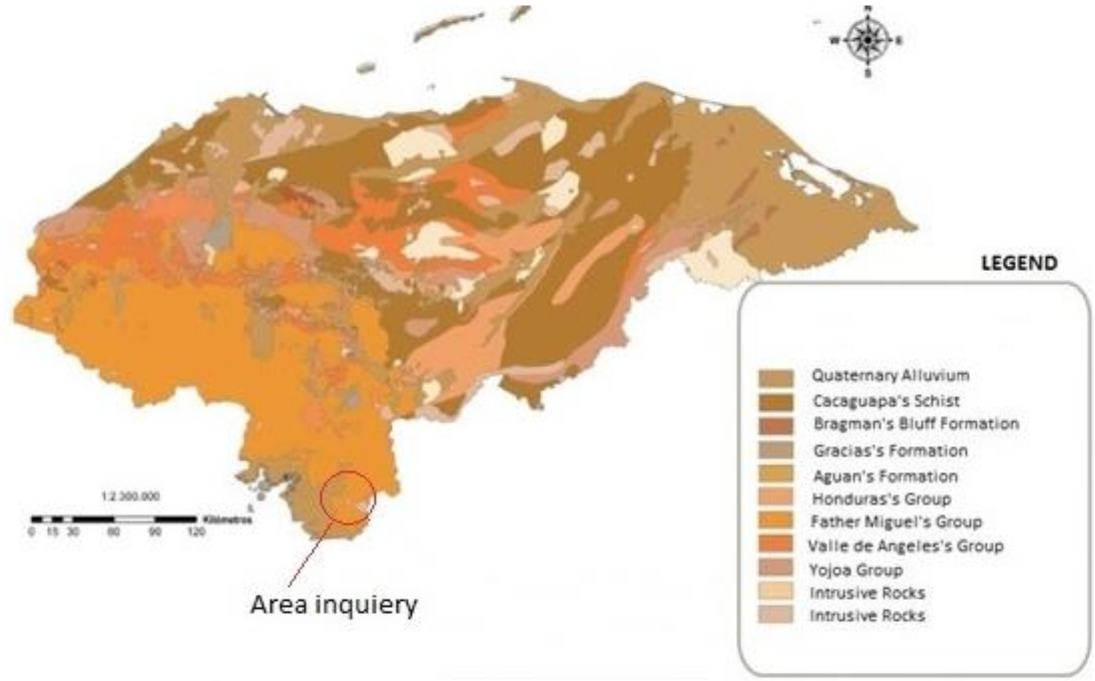

Figure 3: Geological map of Honduras.

In the same way, the zones analyzed in this work are shown in figure 4. The significance of these zones (1-4) is due to these are barely analyzed in Honduras and are the closer to the *Pacific Belt of Fire.*

Figure 4: Research zones location map.

2. Geothermal Development in Central America

Central America has significant geothermal resources, with estimates in megawatt potential ranging from 2,000 to 16,000 MWe. (Lippmann, 2002). However, the installed capacity in Central America is currently only 506.6 MWe, with 26% coming from El Salvador (see Table 2). Table 1 shows estimates by several different authors, most of them estimating slightly less than 3000 MWe.

Table 1. Estimates of geothermal power potential in Central America (IILA, 2010).

Country	MWe			
	Lippmann (2002)	ECLAC (2004)	Lima E. (2005)	SICA (2006)
Nicaragua	1,750	1,200	992	1,000
Costa Rica	1,000	235	750	235
Guatemala	1,000	1,000	480	1,000
El Salvador	500	333	362	450
Honduras	130	120	122	126
Panamá	50	40	42	40
TOTAL	**4,430**	**2,928**	**2,748**	**2,851**

In the region, countries that have advanced in geothermal resources research through the government have more interest in the insertion of geothermal power generation than those countries in which their research has been done by the private sector.

Geothermal exploration in Honduras began in 1976 and has made some progress since that time. An inventory of geothermal sources has been made and detailed research has led to the categorization of various high-enthalpy fields of geothermal interest for electricity production. To date, 204 springs have been identified in Honduras, which have surface temperatures between 30 ^{o}C and 101 ^{o}C (Flores W. et al, 2011).

Table 2. Geothermal Power installed in Central America (IILA, 2010).

Country	Power Installed (Mwe)
El Salvador	204.4
Costa Rica	165.5
Nicaragua	87.5
Guatemala	49.2
TOTAL	**506.6**

3. Methods and Materials

A broad suite of anions and cations from four locations in southern Honduras were analyzed. Table 3 describes the analytical methods that were used.

Table 3. Analytical methods used in this study.

Species	Method of Analysis	Equipment
TEMPERATURE	Direct measurement in field	Thermometer
pH	Direct measurement in field and laboratory	pH meter
CONDUCTIVITY	Direct measurement in field and laboratory	Conductivity meter
NA +, K +, Ca 2 +, Mg 2 +, Li +	Atomic absorption flame air - acetylene and nitrous oxide - acetylene	Atomic Absorption Spectrophotometer
Chloride (Cl-)	Titration with silver nitrate	Volume
Sulphates (S04 2)-	4 Sulfaver /HACH	UV-visible spectrometer
Bicarbonate (HC03)-	Titration by recoil with hydrochloric acid, sodium hydroxide and nitrogen gas	pH meter/volume
Carbonates ($C0_3$)	Titration by recoil with hydrochloric acid, sodium hydroxide and nitrogen gas	pH meter/volume
Carbon dioxide ($C0_2$)	Titration by recoil with hydrochloric acid, sodium hydroxide and nitrogen gas	pH meter/volume
Total alkalinity	Sum of $HC0_3$ and $C0_3$	
Fluorides (F)-	Fluoride selective electrode	Selective electrode
Nitrogen-nitrates (N-N03)	Reduction of cadmium	UV-visible spectrometer
Ammonia nitrogen (NH3-N)	HACH-Salicylate Method	HACH-UV-visible spectrometer
Hydrogen sulfide (H2S)	HACH Methylene blue method	UV-visible spectrometer
Silicon dioxide (Si02)	Silica molybdate	UV-visible spectrometer
δD ‰ yδ 180 ‰	Laser technology	Equipment laser for isotope

The samples collected in this study are divided in four groups and are hydrothermal type (100% water).

The concentrations of the cations: sodium, potassium, calcium, magnesium, silica, and lithium; and anions: bicarbonate, chloride, sulfate, nitrate and fluoride, were analysed following the methods shown in Table 3. The water types were classified based on the piper diagram. 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 Arnnosson (1989) and the sodium-potassium-magnesium geothermometers of Giggenbach (1988).

4. Results

Following, the results of laboratory analysis are shown. Firstly, in table 4 the location coordinates and superficial temperature are shown.

Table 4. Location of representative manifestations in each area.

Province	Location	Zone	UTM Coordinates		Superficial temperature of the manifestation*
			East	North	ºC
Choluteca	Pavana	1	503643	1496423	70.0
	Namasigue	2	486309	1440358	76.5
	Morolica	3	503606	1496195	82.0
	El Triunfo	4	4999409	1441015	80.6

*All manifestations are hydrothermal water spring type

In the table 5, the conductivities that were found in the laboratory, which correspond to the samples object of this study, are presented. Conductivity results show anomalous conditions typical of that of hydrothermal systems in Honduras, with small alteration to the traditional subductive process of the Central American Region.

Table 5. Conductivity by zones (Compilation, laboratory ENEE, 2016)

Zone	Conductivity
	µS/cm
1	**1300**
2	**2070**
3	**2470**
4	**972**

In table 6, the anion concentrations of the hydrothermal samples of this study are shown. In some cases, no specific anions were detected. Methods of visible UV, potentiometric and colorimetric were used.

Table 6. Concentration of anions

Zone	Nitrates N-NO$_3$ mg/L	Ammonium N-NH$_3$ mg/L	Sulfide/Hydrog. H2S µg/L	Sulfates SO_4^{2-} mg/L	Chlorides Cl^- mg/L	Silica SiO2 mg/L	Fluorine F- mg/L
1	0.02	0.01	ND	342	53.98	105.00	3.26
2	ND	ND	82.00	225	495.85	63.70	1.03
3	0.03	0.04	97.00	850	80.77	139.70	5.94
4	ND	ND	38.00	345	35.59	66.90	1.71

Reference: (ENEE`s Laboratory, 2016). ND: Undetectable

Concentrations of cations found for hydrothermal waters using the atomic absorption spectrophotometry method are shown in Table 7.

Table 7. Concentration of cations

Zone	Sodium Na^+ mg/L	Potassium K^+ mg/L	Calcium Ca^{2+} mg/L	Magnesium Mg^{2+} mg/L	Lithium Li mg/L
1	217.83	8.31	25.4	0.14	0.22
2	344.81	8.18	64.69	0.12	0.29
3	422.34	16.81	41.94	0.59	0.89
4	162.05	4.55	26.47	N.D	0.13

Reference: (ENEE`s Laboratory, 2016). ND: Undetectable

In the following table, the concentrations of the alkaline anions of the samples are shown. To obtain this data the potentiometric method was used.

Table 8. Alkalinity.

Zone	Bicarbonates HCO_3	Carbonates CO_3	Carbon dioxide CO_2
1	54.31	ND	46.94
2	14.00	1.53	11.22
3	208.16	ND	150.14
4	13.52	2.47	11.56

Reference: (ENEE`s Laboratory, 2016). ND: Undetectable

Based on their chemical compositions from tables 5 to 8 and the analysis in Piper diagram (see Figure 5), the waters sampled are classified as sodium sulfate waters in areas 1, 3 and 4 and as sodium-chloride water in area 2. In this way, bicarbonate fluids were not found. In Honduras bicarbonate fluids are found in the convergence of North America with Caribbean plates.

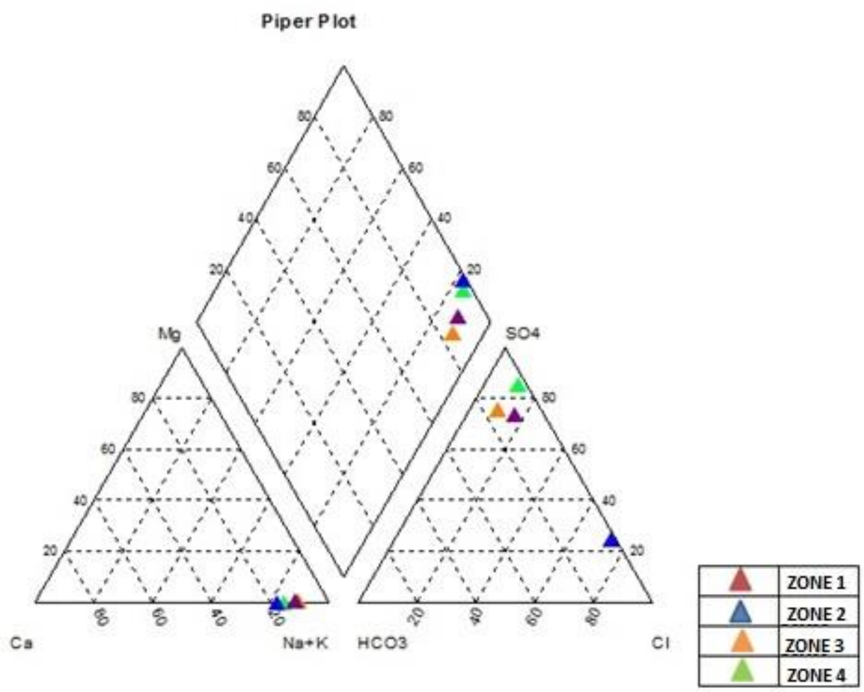

Figure 5: Piper Triangular Diagram (Basic classification of the samples by zones)

5. Geotermometry

Geothermometry results are shown in the Giggenbach-1988 diagram from fig. 6. From this figure, zone 4 is not showed due to undetectable Mg concentrations (see table #7).

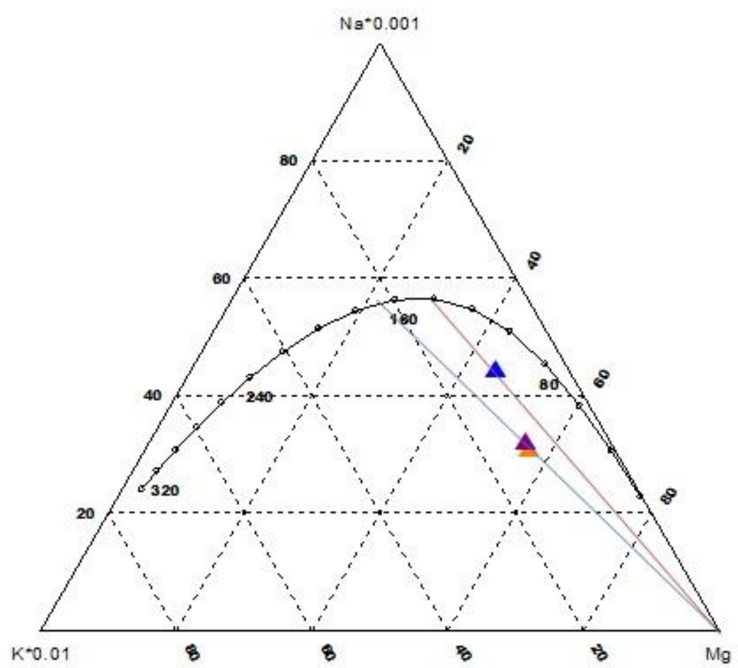

Figure 6: Ternary Na-K-Mg diagram of Giggenbach-1988 for areas 1, 2 and 3.

The following geothermometers were used:

- Silica amorphous
- Quartz
- Na-k (Fournier 1979)
- Na-k (Truesdell 1976)
- Na-k (Arnorsson 1983)
- Sodium-Lithium
- lithium

However, only Na-K geothermometers (Fournier 1979 and Arnorsson 1983) were those that were able to present values within the expected parameters and are presented in fig. 7, i.e. sample concentrations are not meaningful.

Therefore, in figure 5 the Na-K diagram (Fournier 1979 and Arnorsson 1983) is showed.

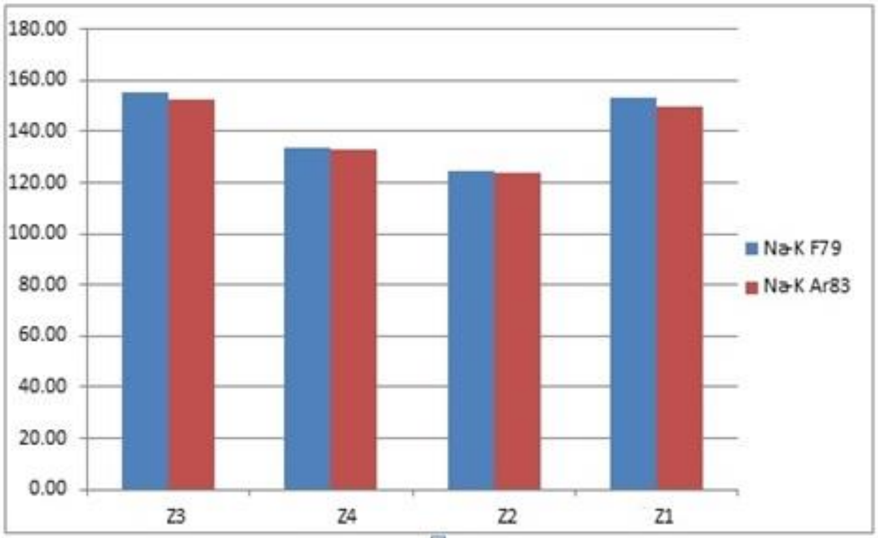

Figure 7: Geothermometers (Alkaline Metals)

6. Isotropic Geochemistry

The following table shows the results of the stable isotopes oxygen 18 and Deuterium present in samples of geothermal waters analysed in each of the selected areas of interest.

Table 9. Concentration of Isotopes, Deuterium and Oxygen 18 (data obtained in laboratory)

	DEUTERIUM	OXYGEN 18
Zone	D per mil	^{18}O per mil
1	-48.73	-6.86
2	-44.98	-6.20
3	-54.10	-7.19
4	-49.84	-6.63

The isotopic diagram in fig. 8 shows the composition of each of the samples compared with meteoric waters from the Berlin geothermal system located in northern El Salvador. The plot shows data from Honduras line nearby to the local meteoric line.

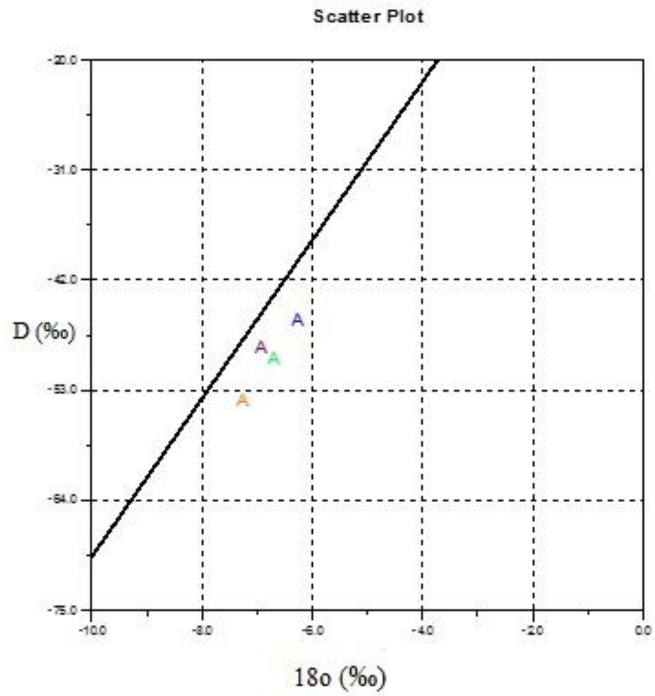

Figure 8: Isotopic compositions of waters from Honduras compared to the meteoric water line from Berlin, El Salvador.

7. Conclusions

- Based on the classification of waters, zone 2 presents different characteristics compared to the rest of zones, and unique in the country. Geothermal systems typical of mature waters and worth studying further.
- This study contributed to the construction of the *Geochemical Conceptual Model* of southern Honduras
- It was determined that the geothermal systems of southern Honduras would be of low and medium enthalpy.

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