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Geochemical Study of Thermal Waters in the Tutupaca Geothermal Zone, Tacna, South of Peru

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ABSTRACT

In this study, representative samples from hot springs were chemically analyzed. Geothermometers were used to calculate the deep temperatures of geothermal reservoirs on the basis of fluid mineral equilibrium. In all cases, the chemical components are not in equilibrium with the minerals in the reservoir, due to the fact that most of these waters are acidic.

Geothermal manifestations in the Tutupaca zone are evidenced by the presence of hot springs, mud pools and fumaroles with temperatures up to 90°C. The pH values range from 2.90 to 6.9 and conductivity from 800 µS/cm to 2900 µS/cm. Geochemical interpretation according to Cl-SO_4-HCO_3 ternary diagram shows that thermal waters are classified as sulphate, sulphate-chloride and bicarbonate waters.

In B-Cl binary diagram the waters of the Tutupaca area are reacting at deep levels with marine sedimentary rocks, which probably have high porosity and permeability and with abundant fractures. The Na-K-Mg triangular diagram was also used to evaluate equilibrium between water and reservoir rocks, showing a linear trend and pointing to an equilibrium temperature of 200°C (Na/K) in the reservoir and fluid dilution or mixing. The δ^2H and δ^{18}O isotopes diagram also show that the thermal waters originate mainly from meteoric water.

According to the geological and geochemical exploration results a conceptual hydro-geochemical model has been proposed for the Tutupaca zone. This model shows a geothermal system associated with magmatic sources from where the geothermal fluids emerge. There is a structural trend which allows the deep circulation of the waters between 2 and 3 km. The chemistry of these thermal waters could be explained by the interaction between the thermal fluid with sedimentary and volcanic rocks.

1. INTRODUCTION

The Tutupaca geothermal zone is located in the Western Cordillera of the Andes, in the Tacna region of Southern Peru. The geothermal zone lies at an altitude between 4000 and 4500 meters (ASL)). In this geothermal area, the presence of the Tutupaca volcanic complex is evident. The Tutupaca volcanic complex (17 ° 01 'S, 70 ° 21' W) is located on the southeastern part of the Peruvian volcanic arc. This volcano is considered active, because several eruptions occurred during historical period. Additionally, volcanic activity reports compiled by the "Global Volcanism Program" (Siebert et al., 2010) suggest that there have been at least 4 eruptions in this area in historic times, in the years (AD) 1787, 1802, 1862 and 1902. Also, the Zamácola (1958) and Valdivia (1874) reports clearly indicate that Tutupaca has had at least two eruptive periods in 1789 and 1802 (Manrique et al, 2012).

The Tutupaca geothermal zone is surrounded by two main rivers, Callazas to the east, and Tacalaya to the west, both controlled by structural lineaments. The weather is cold, typical of the high Andean zone, with maximum temperatures not exceeding 14°C (Instituto Geológico Minero y Metalurgico, 1994). Floristic composition is also quite poor, predominantly stony ground.

In Tutupaca 36 geothermal manifestations of various types were recorded: hot springs, mud pools, fumaroles and steam sources (Fig. 1 and 2). These come from four sectors: Callazas River, Pampa Turun Turun, Tacalaya River and the sulphur_area (Azufre Grande and Azufre Chico).

In Azufre Grande, two areas with geothermal manifestations have been identified; the first is located in the upper part, where there are steam vents, fumaroles and mud pots. These are common on the flanks of active volcanoes as well as in geothermal fields, where temperatures are generally close to the boiling point of water. In this area the temperature is above 80°C, with pH from 2.7 to 4.5. The second area is located in the lower part where there are hot springs with temperatures from 47 °C to 61°C and acidic pH value not exceeding 2.9. The hot springs in Azufre Chico have the same characteristics of those in Azufre Grande. Around the hot spring waters, steam and gas events, yellow crystals of pure sulphur are observed, as well as emissions with a strong H_2S smell.

Also, several hot springs in the Tutupaca area emerge into the Callazas and Tacalaya rivers with temperatures from 20 °C to 57.8°C, and pH values from 6 to 6.9. These springs undergo mixing with river water that possibly contributed to pH neutralization, due to an increase in HCO_3 ion. Furthermore, increased chloride ion concentration is observed in the chemical composition of these waters, unlike in acidic waters.

The aim of this paper is to determine the chemistry and isotopic characteristics of geothermal fluids and the applicability of chemical geothermometers to calculate deep temperature. The results are interpreted, focusing on origin of fluids, and the formulation of a conceptual model for Tutupaca zone. This will provide useful information in the exploitation and utilization of these geothermal resources.

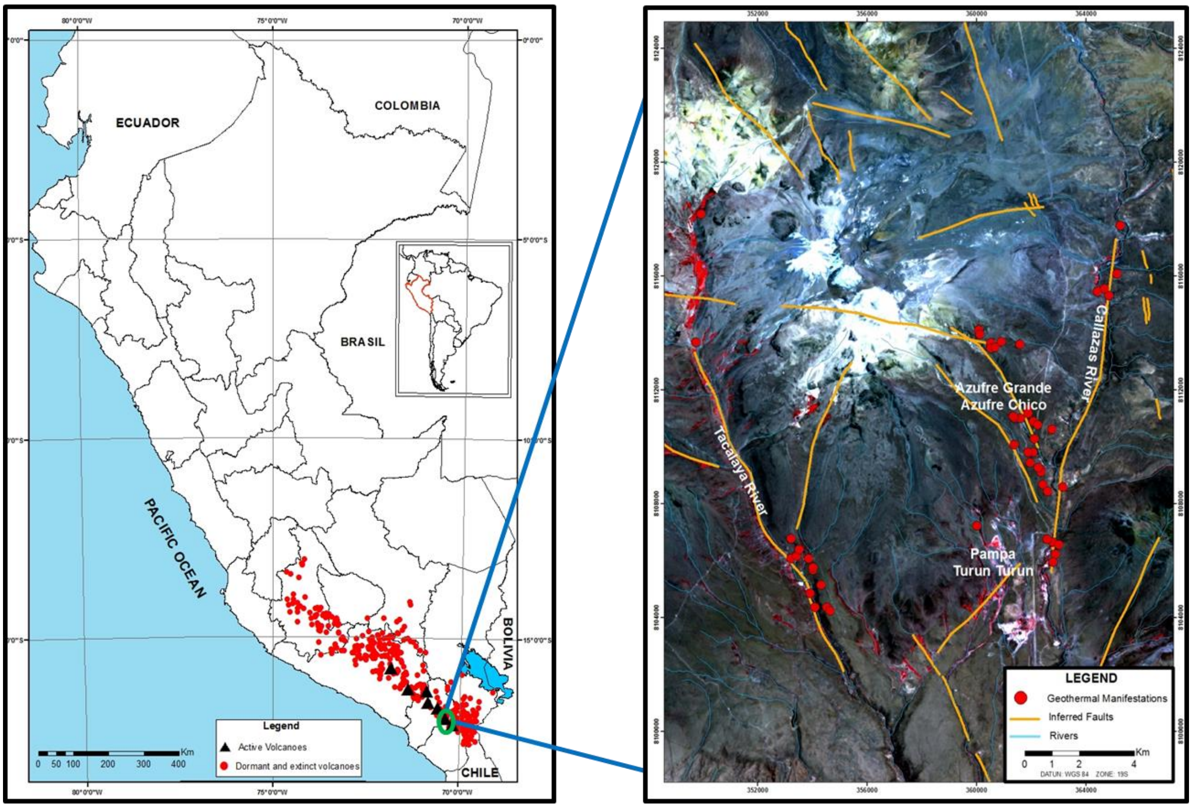


Figure 1: Map showing locations of the thermal waters in the Tutupaca field.

Figure 2: View of geothermal manifestations in Azufre Chico, close to Tutupaca volcano.

2. GEOLOGICAL SETTING

In the Tutupaca geothermal area, volcanic rocks are observed corresponding to Tutupaca active volcano. This volcano is situated upon a substrate composed of Huaylillas Formation ignimbrites, which have been dated between 12-24 Ma. Furthermore, volcanic rocks of the Upper Cretaceous to Pliocene, like the Toquepala Group, Barroso Group and Sencca Formation (Manrique et al, 2012) were identified near the volcano.

The Tutupaca volcano consists of an alternating sequence of pumice pyroclastic flows and ash with massive blocks. It is followed by an important sequence of andesitic and trachytic lavas flows, and finally a trachyandesitics debris flow tuff with abundant hornblende crystals containing, biotite, pyroxene and quartz (De la Cruz and De la Cruz, 2001).

Beneath these rocks and in the southern part of the volcano outcrops the Huaylillas Formation (Miocene) (Fig.3) which consists of pyroclastic flows, rhyolitic tuffs and andesite blocks. In the Tutupaca area, some deposits precipitated to the Turun Turun sectors and Tacalaya were also identified. The result of precipitation from hot springs are characterized by amorphous silica sinter, altered zones are found preferably in different systems of intersection of tectonic structures and around volcanic structures, also the central zone of the volcano Tutupaca has hydrothermal alteration zones.

In the Tutupaca area, the stratigraphy, geological structures and the distribution of surface thermal manifestations, indicate that geothermal fluid flows are controlled by permeable zones associated with faults. In the Tutupaca geothermal area, the structural context is characterized mainly by regional NW-SE guidelines and local NNW-SSE and NNE-SSW faults that control the location of hydrothermal systems (Fig. 1). The identification of the Tutupaca fault with NE-SW direction indicates that large fracturing seems to control fissure volcanism (Torres, et. al. 1997).

The local NNW-SSE structures seem to determine the upwelling of geothermal manifestations as in the case of streams Azufre Grande and Azufre Chico. De la Cruz (2001) describe a large geological lineament, which determines the course of the Tacalaya river.

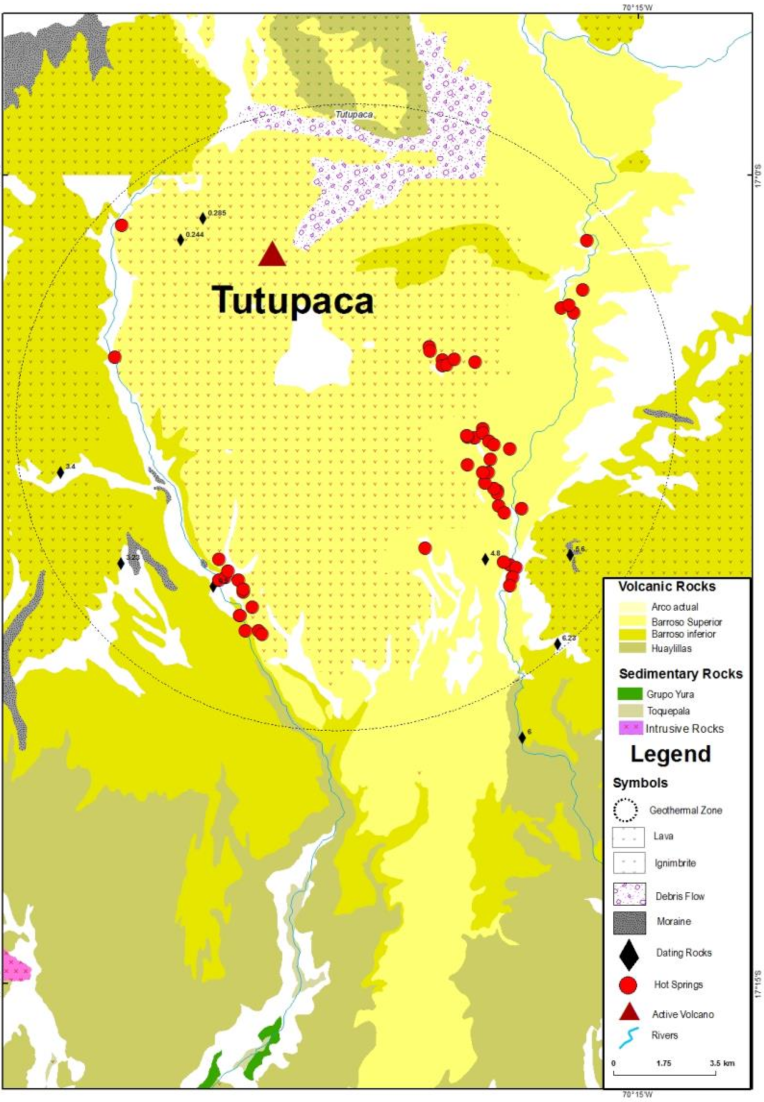


Figure 3: Tutupaca Geological Map.

3. CHEMICAL COMPOSITION OF THE GEOTHERMAL FLUID

3.1. Sampling and Analysis

Geochemical studies of geothermal fluids involve three main steps: 1) sample collection, 2) chemical analysis and 3) data interpretation.

3.1.1. Sampling

Water samples were collected for this research during a field campaign conducted in July and August, 2010. The waters around the Tutupaca volcano have temperatures between 20°C to 66°C. Samples were collected for chemical and isotopic analyses.

Three (3) types of samples were collected: one sample for the analysis of cations that were preserved by adding hydrochloric acid; a second sample without hydrochloric acid (non-preserved sample) for analyses of anions. The third sample was used to determine isotopic composition. These samples have established a basis for explaining the chemistry of hot springs in the geothermal Tutupaca field.

The chemical composition of the water samples were analyzed in a certified and accredited laboratory in Lima, Peru and by the West Japan Engineering Consultants, Inc. in Japan. For deuterium (δD) and oxygen-18 (^{18}O) isotope analysis, this was carried out by the Chilean Nuclear Energy Commission-CCHEN laboratory.

3.1.2. Analysis on Site

Temperature

In-situ temperature measurement was performed using a portable VWR brand digital thermometer with a precision of ± 0,1°C.

Conductivity

Conductivity of the samples was measured along with temperature using a WTW brand Model 340i conductivity meter with a resolution of 1 μS/cm. Since conductivity is as a function of temperature, this was measured at a uniform temperature of 25°C.

pH

Measurement pH was performed using multi-parameter WTW brand Model 340i with an accuracy of ± 0.1. Also, it has become instrument of control using test strips capable of determining pH ranges as narrow as possible.

3.2. Analytical Results

Tutupaca hot springs are located in the valleys of Azufre Grande and Azufre Chico and in the Tacalaya zone and along the river Callazas at an altitude of 4200 meters and 4070 meters above sea level respectively (Fig.1). The thermal springs located in Azufre Grande and Azufre Chico discharge to the Callazas River and those of Tacalaya to the Tacalaya River. Warm waters also appear in the Turun Turun area.

The results of chemical analysis and isotopic composition of water samples from springs in the Tutupaca geothermal zone are shown in Table 1. Ion balances for the samples were calculated over based on percentage of weight balance in the samples.

The temperature of these sources varies between 49°C and 62°C, pH range from 2.6 to 6.9, and electrical conductivity from 2.3 to 2.9 mS/cm. The hot springs of Azufre Grande and Chico have high SO_4 ion concentrations from 763-1214 mg/L, being the dominant ion in the chemical composition characteristic of volcanic waters, while Tacalaya, Callazas and Turun Turun hot springs show HCO_3 as dominant ion (Table 1).

3.2.1. Classification of the Fluids

In Figure 4, the relative composition of the dominant anions Cl-SO_4- HCO_3 (Giggenbach, 1988) for hot springs in the Tutupaca area, shows that the samples of Azufre Grande and Chico lies mainly on the sulphate region of the ternary plot, characteristic of acidic volcanic water, associated with the hydrothermal system of the Tutupaca volcano.

Tacalaya and Callazas waters are located in a bicarbonate region of the plot typical of water diluted or mixed with surface water. This suggests that these waters are the product of the dilution of chloride water with bicarbonate water; during prolonged lateral flow (Nicholson, 1993).

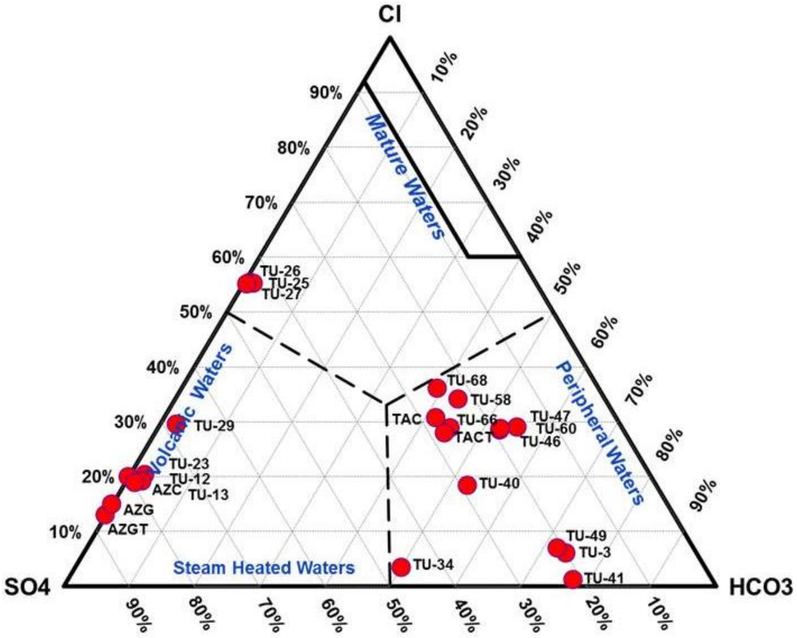


Figure 4: Cl-SO_4-HCO_3 ternary diagram (Giggenbach, 1988).

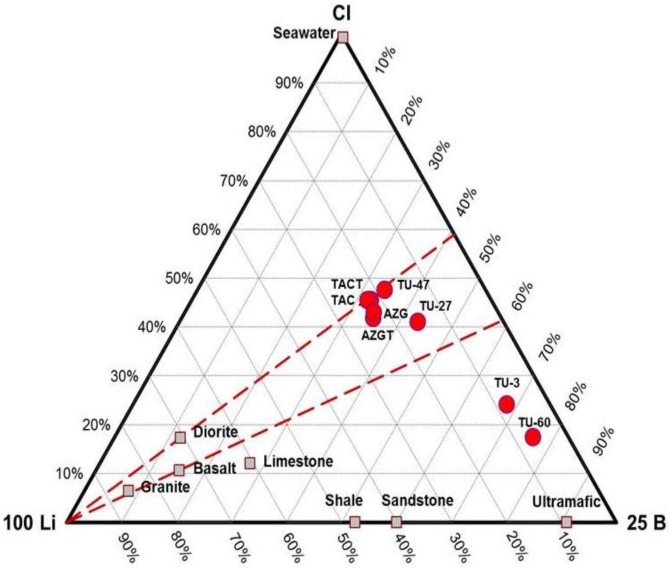
Lithium is the alkali metal least affected by secondary processes. It is therefore used as a tracer for the initial deep rock dissolution process and to evaluate the possible origin of two important conservative constituents of geothermal water. The boron content of thermal fluids reflects the degree of maturity of a geothermal system. It is expelled during the early stages of heating up due to its volatility. Fluids from older hydrothermal systems therefore have less boron content but higher content for younger hydrothermal systems.

At high temperatures, chloride occurs as hydrochloric acid (HCl) and boron as boric acid (H_3BO_3), and both are volatile and able to be mobilized by high temperature steam. At lower temperatures, the acidity of HCl rapidly increases and it is changed by the rock to the less volatile NaCl but B remains in its volatile form and is carried to the surface in the vapor phase. The Cl/B ratio is used to indicate a common reservoir source for the waters. Caution should, however, be taken in applying this interpretation because waters from the same reservoir can show differences in Cl/B ratio due to lithology changes at depth in a field (e.g. the introduction of a sedimentary horizon), or by the absorption of B into clays during lateral flow.

The Cl-Li-B ternary diagram (Fig. 5) shows that the water has a tendency towards B corner, which would indicate the thermal water samples, could come from a relatively young hydrothermal system with absorption of high B/Cl magmatic vapor into the system. Furthermore, the concentration of B in the geothermal waters is from 4-62 mg/L, with atomic ratio B/Cl of 0.08 to 0.5. Figure 6 shows that the waters of geothermal Tutupaca would react with marine sedimentary rocks at deep levels, which probably have relatively high porosity and permeability with abundant fractures (Shigeno et al., 1993; Shigeno and Abe 1983). It is possible that hot waters in Tutupaca zone have greater opportunity to interact with and leach boron-bearing host rocks because of relatively deep circulation paths. Excessively high boron concentrations have been documented for geothermal systems flowing through boron-rich sedimentary rocks (e. g, Aggarwal et al., 2003).

On the other hand, we can also mention that the high B concentration is possibly related with young volcanism, in this case with Tutupaca volcano, associated with dissolution of volcanic gases into the hot water influenced by magmatic temperatures where B and Cl form volatile compounds. This could also indicate that in the Tutupaca geothermal zone, the higher B/Cl ratio could be favored by magmatic heating or cooling intrusions (Arehart et al., 2003).

Precipitates of yellow, red and whitish colored sulfur was likewise observed around the acidic hot springs. This can take place as: (1) precipitation of SO_4-minerals (mainly gypsum, alunite and jarosite) and elemental S; and (2) bacterial reduction of SO_4^{2-} to S^{2-} and precipitation of sulfide minerals. However, the leaching process in the zone may be negligible due to low Li concentration present in the hot waters (Martini et al., 1994).



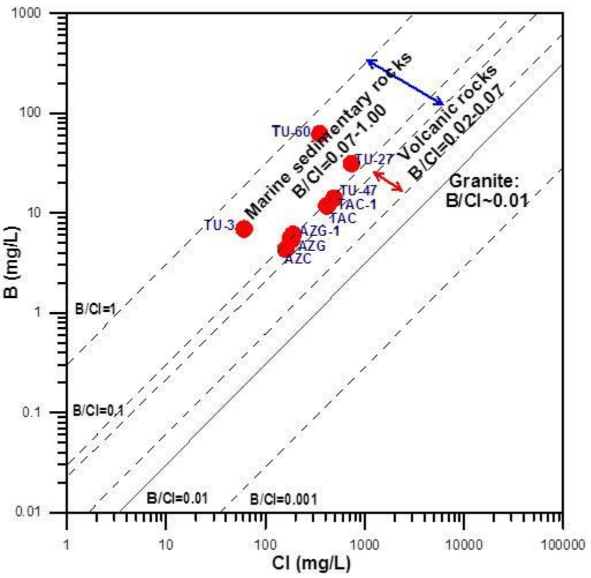


Figure 5: Cl-Li-B ternary diagram (Giggenbach, 1998).

Figure 6: Boron vs Chloride diagram (Shigeno, 1993).

3.2.2. Geothermometers

The purpose of the geothermometers is to estimate the temperature of the resource fluid at depth, given the concentrations of dissolved substances from the surface samples. This method assumes that concentrations at depth are preserved as the waters flow to the surface, and measures the degree to which the substances were in equilibrium at depth. Geothermometer calculations are empirical, but in most cases seem to give a reasonable estimate.

The Na-K-Mg ternary diagram (Fig. 7) shows that the Tacalaya and Callazas waters that tend towards partial equilibrium. This would indicate minerals that has dissolved but not attained equilibrium, or geothermal water suffering dilution or mixing with cold water.

Data points that plot close to the √Mg corner usually indicate a high proportion of cold groundwater, not necessarily immature waters. The Azufre Grande, Azufre Chico and Turun Turun hot springs have a high percentage of Mg, implying that these waters have not attained equilibrium with the reservoir rocks or perhaps these waters were influenced by shallow processes and possible equilibration at lower temperature. However, the higher concentrations of Mg also can indicate near-surface reactions leaching Mg from the local rock, or dilution by groundwater which can be relatively Mg- rich (Nicholson, 1993). In the case of Azufre Grande, Azufre Chico and Turun Turun the hot springs are acidic. The high percentage of Mg could be related to leaching process of the rock.

The Na-K-Mg diagram indicates a linear trend pointing a Na/K equilibrium temperature of 200°C in the reservoir. The linear trend observed is either due to dilution or mixing. Table 2 and Figure 9 also show the results of calculated temperatures using chemical geothermometers.

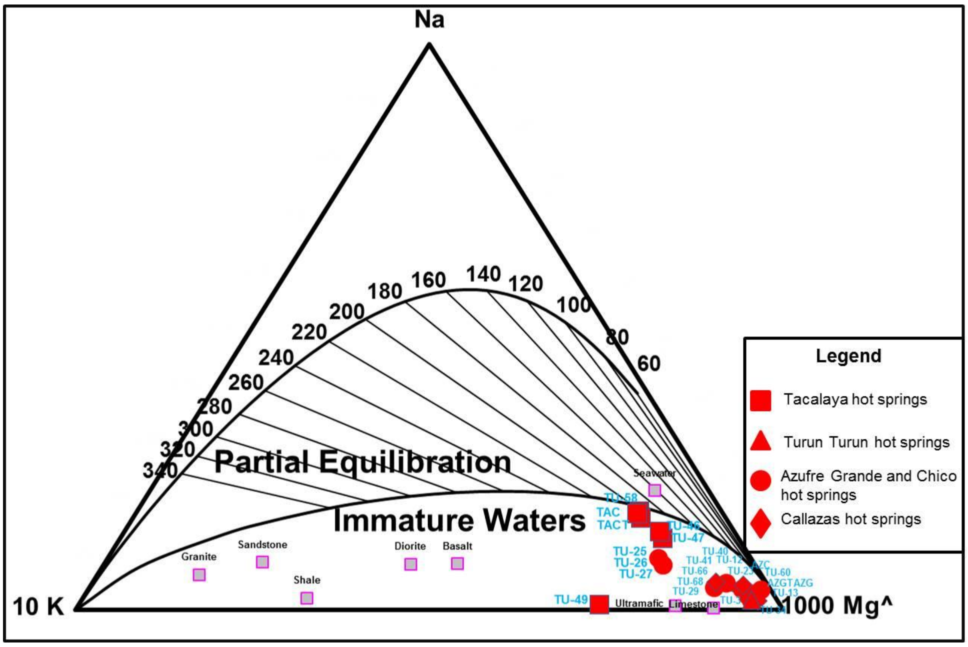


Figure 7: Na-K-Mg Ternary diagram (Giggenbach, 1983).

On the other hand, Na-K-Mg geoindicator (Fig. 7) shows that Tacalaya waters have a tendency towards the equilibrium line. By making a vertical projection, the liquid is exposed to elevated temperatures of over 200°C.

Figure 8 represents the estimated temperature of the Tutupaca geothermal system reservoir from liquid phase geothermometers. The values indicate that the reservoir temperature is above 200°C, classifying it as a system of intermediate to high enthalpy and can be used for power generation.

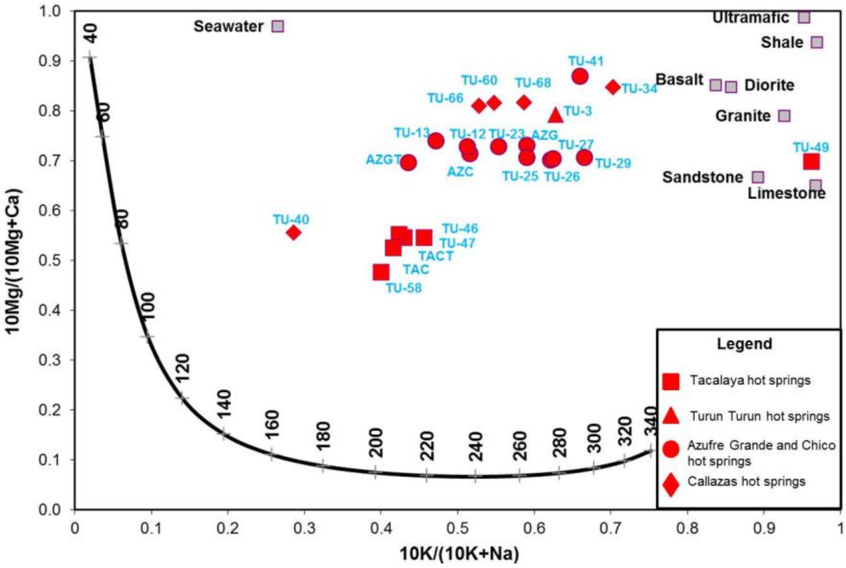


Figure 8: Na-K/Mg-Ca Diagram.

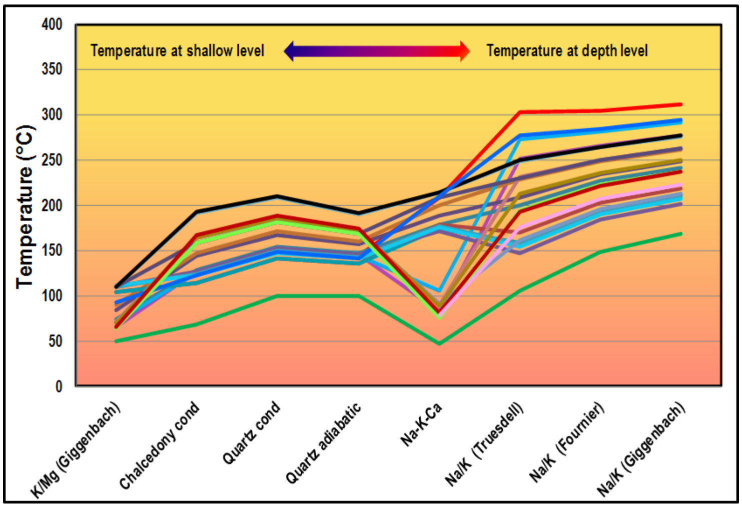


Figure 9: Estimated temperatures based on geothermometry (Table 2).

3.2.3. Chloride-Enthalpy mixing model

The chloride-enthalpy diagram proposed by Fournier (1979b) (Fig. 10), shows that the hot springs are located in the dilution or mixing line. This indicates that ascending deep hot water is boiled and then mixed with cold water at shallow depth. In Tacalaya, Azufre Grande and Chico it is clearly noted that the chloride concentration is relatively low, while SO_4 and HCO_3 are high. These elements are invariably superficial fluids formed by the condensation of geothermal gases in groundwater near the surface.

4. ISOTOPIC RESULTS

The water samples were analyzed to determine isotopic ratios of δ^2H and δ^{18}O isotopes (Table 1). The thermal waters of Tutupaca graphed in Figure 11 show that these plot close to Local Meteoric Line (Cortecci et al ., 2005), indicating that these are basically meteoric waters. The relationship between all the waters around the Tutupaca field can be summarized by a three end-member mixing model consisting of: 1) a deep chloride reservoir component, 2) a cold or fresh water component, and 3) a volcanic fluids component.

The plot of hydrogen and oxygen isotopic composition with respect to chloride concentration (Figs. 12 and 13) indicate that the origin of the water in the Tutupaca geothermal reservoir is from the mixing of meteoric water with volcanic fluid associated with the hydrothermal system of the Tutupaca volcano. Magmatic water ratio in the reservoir is too low and is estimated to be around 2%.

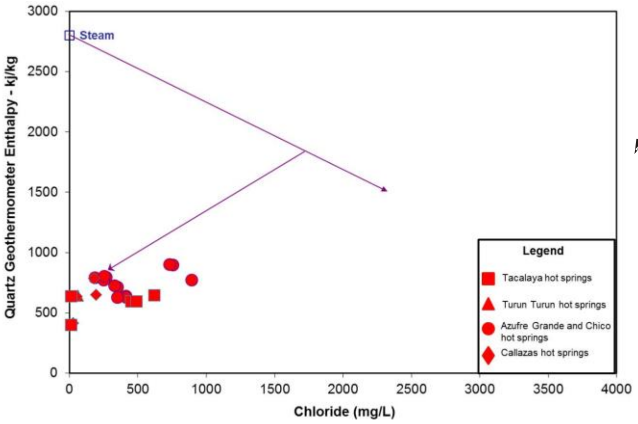


Figure 10: Plot of Chloride versus Enthalpy.

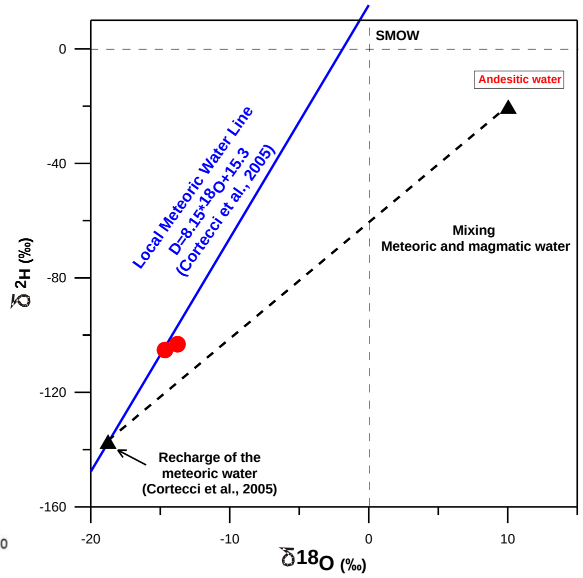


Figure 11: Plot of δ^2H vs δ^{18}O in the Tutupaca zone.

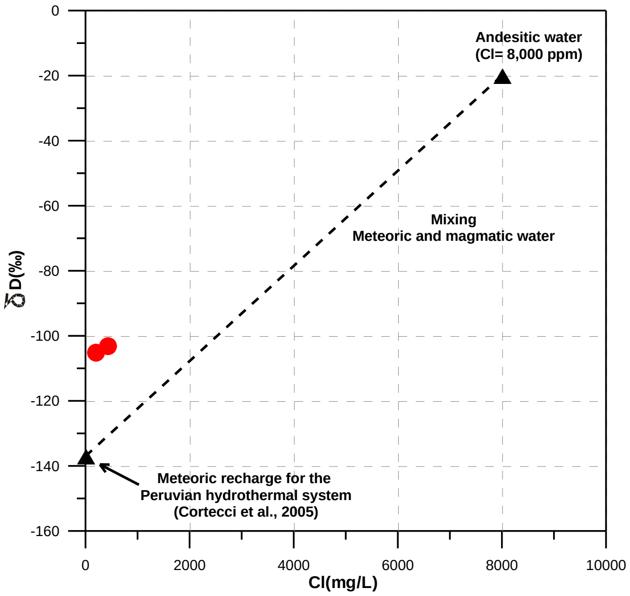


Figure 12: Plot of δ^2H vs Chloride in the Tutupaca zone.

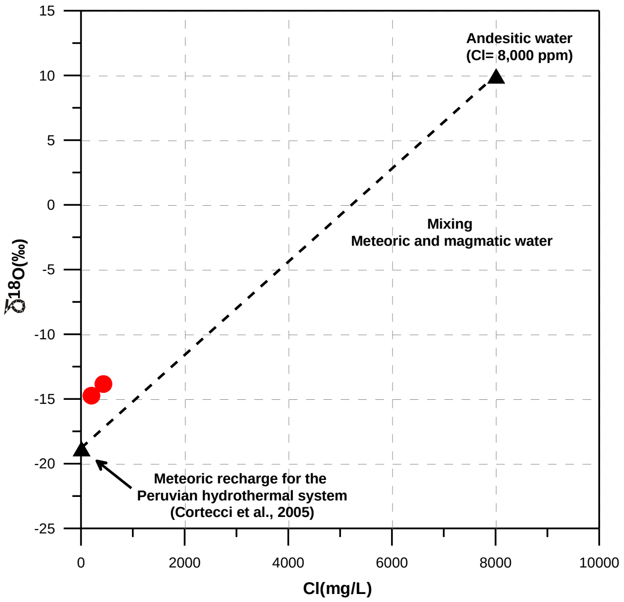


Figure 13: Plot of δ^{18}O vs Chloride in the Tutupaca zone.

5. CONCEPTUAL MODEL

The conceptual model of the geothermal system in the Tutupaca zone is shown in Figure 14. This field is located in the Western Cordillera of the Andes in the southern part of Peru, where Neogene to Quaternary volcanism occurred. The Tutupaca volcanic complex is located at an altitude of 5,815 meters (ASL). The stratovolcano with fumarolic activity at the summit experienced eruptions in 1780, 1802, 1862 and 1902, 1994 in Holocene period as reported by Simkin and Sibert (1994). It is suggested that the heat source in the Tutupaca geothermal system could be related to the volcanic activity of Tutupaca in the Quaternary period.

Permeable zones in geothermal systems are regularly associated with geothermal fluid paths and productivity. Considering the stratigraphy, the geological structures and the distribution of thermal manifestations on surface, these suggest that geothermal fluid flow are controlled by permeable zones associated with faults. Faults play an important role in vertical permeability of geothermal systems. In the Tutupaca geothermal field, the NNW-SSE trending faults dominate the field and are known as Azufre Grande and Azufre Chico faults (De la Cruz and De la Cruz, 2001).

The study of the isotopic composition of δ^2H vs δ^{18}O, as well as the Cl concentration in the hot springs, indicate that water in the geothermal reservoir of Tutupaca, originated from mixing of meteoric water with magmatic water. The high relative concentration of B and the B/Cl atomic ratio of 0.1 indicate that the thermal fluid circulated in deep levels where there are sedimentary rocks that have relatively high B content.

Meteoric water infiltrated to deep levels from the north altiplanic mountainous area. Towards the east it is heated to over 200°C by the conductive heat from magma bodies related to Quaternary volcanism and by mixing with hot magmatic fluid. It is believed that geothermal fluid circulating in the Mesozoic marine sedimentary rocks ascends upwards through permeable zones related to the Azufre Grande and Azufre Chico faults.

Geothermometers used in the spring waters that naturally discharge to the surface estimate the reservoir temperature to be over 200°C. The warm geothermal water rising to a lower level is saturated and partially evaporates due to the loss of pressure. The steam and gases reach the surface near the Azufre Grande and Azufre Chico. At the top of the Azufre Grande several areas of fumarole emissions and mud pots were observed.

The Azufre Grande and Chico springs originated from a shallow aquifer which is heated by steam and gases that come from Tutupaca hydrothermal system. This results in the formation of acidic hot springs. The hot geothermal water that reach shallow level near Azufre Grande and Chico flows laterally in E and SE direction along faults. Laterally flowing hot water is diluted and cooled either by fresh water or shallow groundwater as well as by river water. This diluted and cooled warm water discharge on the surface along the Callazas River.

Also, the waters associated with the hydrothermal system of Tutupaca volcano flow laterally in S and SE direction and emerge at the surface in the Tacalaya and in Turun Turun, favored by the existing fault system in this area.

It is possible that the minimum area is found in the upper streams of Azufre Grande and Azufre Chico. Some permeable zones considered as the main conduits for thermal fluid ascent from the depths in this area are outlined and delineated. The Callazas, Tacalaya and Turun Turun manifestations would be included in the maximum area.

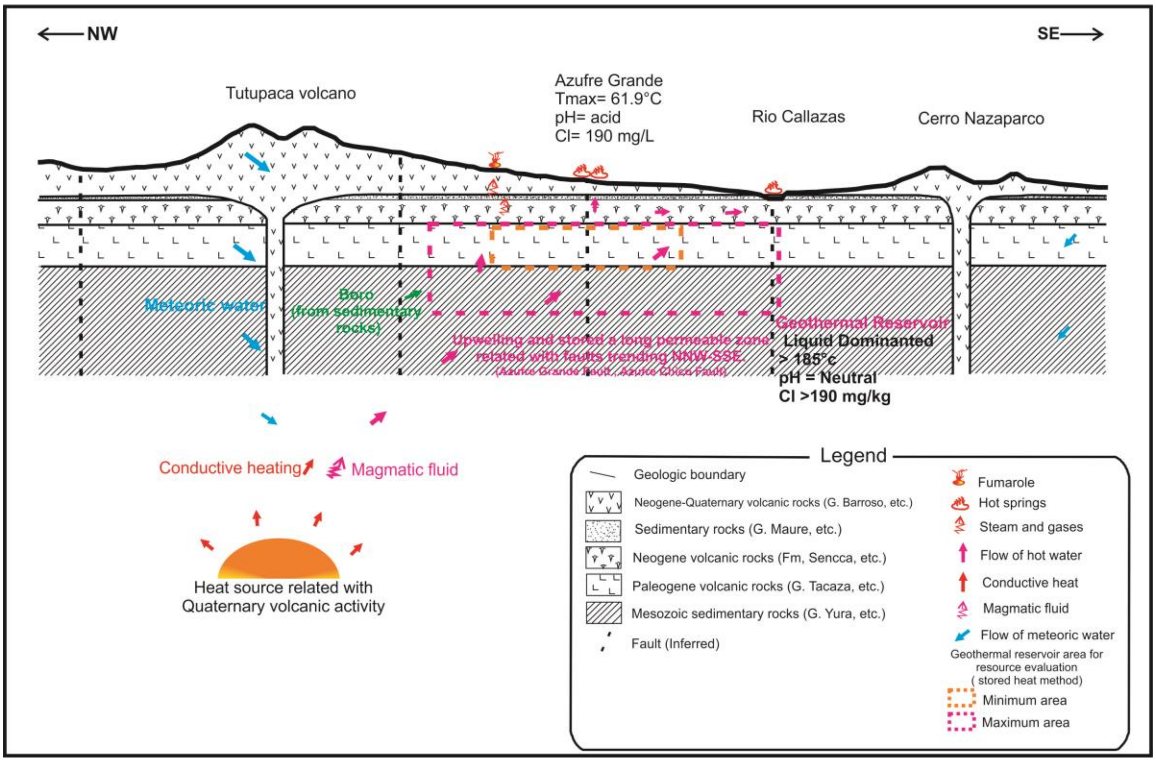


Figure 14: Conceptual model of Tutupaca geothermal zone (West Japan Engineering Consultants, 2012).

6. CONCLUSION

The geochemical characterizations of the thermal springs in the Tutupaca field are summarized as follows:

- The hot springs are classified as sulphate, sulphate-chloride and bicarbonate water.
- Stable isotopes (δ^2H vs δ^{18}O) relationship proves that thermal waters originate mainly from meteoric water but are mixing with magmatic waters.
- The estimated aquifer temperature of the geothermal resource is higher than 200°C.

Sulfatara or sulphur deposits are present in the geothermal field and fumaroles exist at the summit of the active Tutupaca volcano.

According to the geothermal manifestation and estimated subsurface temperature by geothermometers, the geothermal resources in this field seem to be promising.

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Table 1: Chemical composition of the thermal waters in Tutupaca zone.

Hot Springs	Code	Temp °C	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO4 (mg/L)	HCO3 (mg/L)	SiO2 (mg/L)	B (mg/L)	δ^{18}O‰	δ^{2}H‰
Turun Turun	TU-3	25.5	5.5	0.2	83	14	63.0	24.00	61	201	749	130	7	_	_
Rio Callazas	TU-34	23.6	6	0.2	110	26	83.0	46.00	53	745	804	126	_	_	_
Rio Callazas	TU-40	20.5	6	0.1	50	2	16.0	2.00	26	41	75	47			
Rio Callazas	TU-60	52.1	6.5	1.3	248	30	52.0	23.00	353	195	672	165	62	_	_
Rio Callazas	TU-66	35.4	6.5	0.8	170	19	47.0	20.00	194	177	302	133	_	_	_
Rio Callazas	TU-68	20.2	5.5	1.6	275	39	54.0	24.00	332	227	362	173	_		
Tacalaya Norte	TU-41	24.3	5.5	_	118	23	58.0	38.00	11	214	779	126	_	_	_
Tacalaya Sur	TU-46	43.6	6.5	1.8	405	34	50.0	6.00	452	300	837	107	_	_	_
Tacalaya Sur	TU-47	46	6.5	1.9	450	34	50.0	6.00	490	319	903	107	14	_	_
Tacalaya Sur	TU-49	_	_	_	24	60	13.0	3.00	11	33	115	43	_	_	_
Tacalaya Sur	TU-58	55.3	6.5	2.5	600	40	66.0	6.00	622	409	793	130	_	_	_
Tacalaya	TACT	57.8	6.90	2	639	47	65.0	8.00	415	412	662	125	12	_	_
Tacalaya	TAC	57.7	6.91	2.09	590	42	54.7	6.04	421	379	575	120	12	-13.8	-103
Azufre Grande	AZGT	62.6	2.90	1	310	24	185.0	42.00	179	1206	_	213	6	_	_
Azufre Grande	AZG	61.9	2.71	_	173	25	156.4	42.13	190	1082	_	214	6	-14.7	-105
Azufre Grande	TU-23	66.1	4.5	0.7	185	23	150.0	40.00	271	1033	32	216	_	_	_
Azufre Grande	TU-25	48	4.5	2.9	575	83	105.0	25.00	897	710	15	201	_	_	_
Azufre Grande	TU-26	_		2.8	455	75	90.0	21.00	760	597	21	293	_	_	_
Azufre Grande	TU-27	63.3	4.5	2.8	450	75	89.0	21.00	735	592	8	298	31	_	_
Azufre Grande	TU-29	47.6	4.5	1	250	50	138.0	33.00	354	816	32	121	_	_	_
Azufre Chico	AZC	49.2	3.60	0.57	163	17	165.0	41.00	255	1031	_	_	_	_	_
Azufre Chico	TU-12	45.6		0.8	180	19	150.0	40.00	256	1051	33	201	_	_	_
Azufre Chico	TU-13	49.8		0.7	190	17	153.0	43.00	257	1090	21	222	_	_	_

Table 2: Estimated temperature by chemical geothermometry.

Hot Springs	Code	Chalcedony cond	Quartz cond	Quartz adiabatic	Na-K-Ca	Na/K (Fournier)	Na/K (Truesdell)	Na/K (Giggenbach)	K/Mg (Giggenbach)
Turun Turun	TU-3	127	153	145	83	266	252	278	65
Rio Callazas	TU-34	125	151	144	208	304	304	312	72
Rio Callazas	TU-40	69	99	100	47	149	106	168	50
Rio Callazas	TU-60	144	168	158	189	234	209	248	84
Rio Callazas	TU-66	129	154	147	179	227	200	241	74
Rio Callazas	TU-68	148	171	160	200	249	229	262	90
Tacalaya Norte	TU-41	125	151	144	106	282	273	292	71
Tacalaya Sur	TU-46	115	141	136	179	202	169	219	105
Tacalaya Sur	TU-47	115	141	136	175	194	159	211	105
Tacalaya Sur	TU-58	127	153	145	171	185	148	202	110
Tacalaya	TACT	125	150	143	177	192	157	209	110
Tacalaya	TAC	122	148	141	176	189	154	207	111
Azufre Grande	AZGT	164	185	172	91	196	162	213	71
Azufre Grande	AZG	164	185	172	90	251	231	264	72
Azufre Grande	TU-23	165	186	172	89	236	212	250	71
Azufre Grande	TU-25	159	181	168	209	251	231	263	110
Azufre Grande	TU-26	191	209	190	214	264	248	276	110
Azufre Grande	TU-27	193	210	191	215	265	250	277	110
Azufre Grande	TU-29	123	148	142	209	285	277	294	92
Azufre Chico	AZC				76	223	195	238	64
Azufre Chico	TU-12	159	181	168	82	222	193	237	66
Azufre Chico	TU-13	167	188	174	79	208	176	224	63