GEOCHEMICAL CONCEPTUAL MODEL OF BERLIN GEOTHERMAL FIELD, EL SALVADOR, C. A.

José Tenorio Mejía.
Comisión Ejecutiva Hidroeléctrica del Rio Lempa, CEL, 9a C.Pte. 950, Centro de Gobiemo, San Salvador.

Abstract

*The geochemical study of the current analytical information of waters and gases as well as deep temperature data of wells of the geothermal system of Berlin, it has given as a result the conceptual model of the system. The water of the reservoir enters to the systemfrom the bottom **(upflow) from** the south and thenflows with N-NW direction. While itflows in the indicated direction, thejluid is cooled by processes, predominantly of boiling and steam losses,producing the fluid thatfeeds the wells TR-2, TR-3, TR-9, TR-I.*

The evidence indicates that exists boiling in the bottom of the well TR-3 or in thefluid thatfeeds it, in such a way that the chemical species, at reservoir condition, have been concentrated This boiling produces steam and gases that upon ascending are mixed with an intermediate aqufer (approximately 0 masl) in which the sulfidric gas dilutingprovoking an increase in the sulfate concentration of the aqufer. In the same zone but to a depth of 740 masl approxitnately, part of the steam - gas mixture originated from the deeper part, is condensed in the regional aquifer. The spring 83 is the principal representative of such waters with sulfate composition.

The geothermal water mixed with water of the intermediate aquifer moves toward the NNW apparently without subsequent dilutions until emerges in the banks of the Lempa river, where is produced a low mixture with superficial water to produce thejluid thatfeeds the hot spring 20.

*The isotopic preliminary results support the affirmation of the fact that the deep jluid of the well TR-5 originates thefluid of the remaining wells. **In** the same way, the isotopic results would support the affirmation of the fact that in the surroundings of the well TR-3 exists boiling.*

1.0 INTRODUCTION

The Berlin geothermal field is located aproximately 3 kilometers North from the Berlin city, with an elevation between 600 and 900 masl (figure 1). The field is located on the South edge of the central graben of El Salvador and it is associated with the activity of the Berlin volcano. The field is crossed by multiple faults with NNO-SSE direction. The information obtained from the geoscientific surveys carried out in the area, gave cause for the drill of exploratory wells and deep wells, which demonstrated the existence of a deep saline reservoir, liquid dominant and with base temperature of 300 °C. Currently are installed two well-head units of **5** MW each one, those which use the fluid of the wells TR-2 and TR -9. The residual liquid is reinjected in the wells TR-1, TR-8 and **TR-14.**

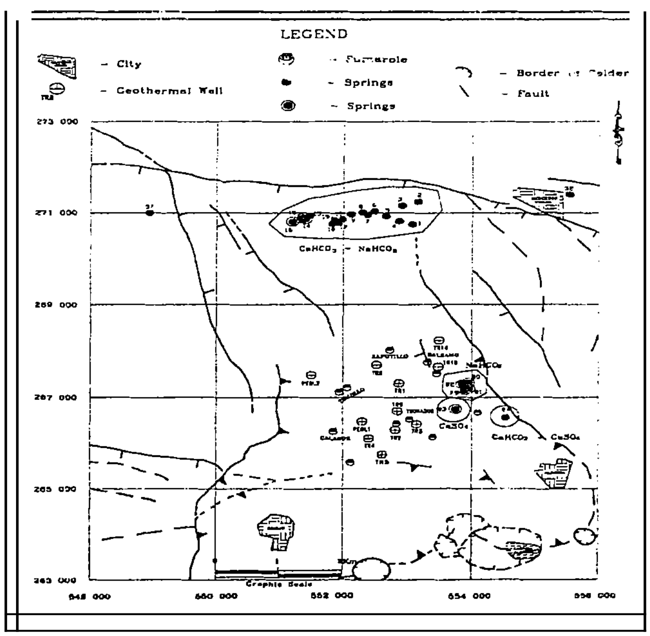

Figure 1. Location **of** Berlin geothermal field.

2.0 WATER CHEMISTRY

2.1. Shallow waters. The shallow springs and domestic wells of the area, are located mostly northward, northeast and northwest of the Geothermal Field, as is observed in the figure 1. Chemically, the waters of the area of Berlin are classified into three main groups:

Bicarbonate waters: they are those of origin thoroughly superficial or meteoric. Most of springs toward the north and northwest of the field correspond to this classification.

Sulphate waters: in most of geothermal systems, these waters are of superficial origin, those which contain low chloride content. The pH of 2-5 is produced by superficial or shallow secondary processes, such as reaction with gases that emerge from the depth. This aquifer is evidenced by the spring **83** mainly.

Waters with sodium - chloride composition: typical of deep waters in high temperature systems, associated with volcanic areas. They are represented by the geothermal waters.

The figure 2 shows the triangular diagram used for the classification of the waters in the area of Berlin. The superficial waters are located in the lower right comer. These waters have as prevailing anion the bicarbonate and compris most of the sprigs of the area, cold and hot. The sulphate waters are represented by the samples of the spring **83,** near the fumarole El Tronador, and the Laguna de Alegria. The geothermal waters are located in the upper comer, corresponding to the NaCl waters type. The graph shows also certain mixture patterns between the geothermal waters and the sulphates to produce the fluid represented by the spring 20, that also contain certain proportion of bicarbonate waters.

According to the map location shown in the figure 1, it migh said that the flow pattern toward the northwest cfthe field is in agreement with the direction of the principal regional systcm faults of the system. Probably the waters initially mixed in the zone of the field (waters NaCl - SO,), find some type of impermeable barrier, that prevents its subsequent mixes with superficial waters, but that thev are heated conductively. The fluid of the spring 20 would have been mixed with bicarbonate water: in some section of its flow path, far from its rise. This would be explained by the impermeability already mentioned of the strata located toward the northwest of the system.

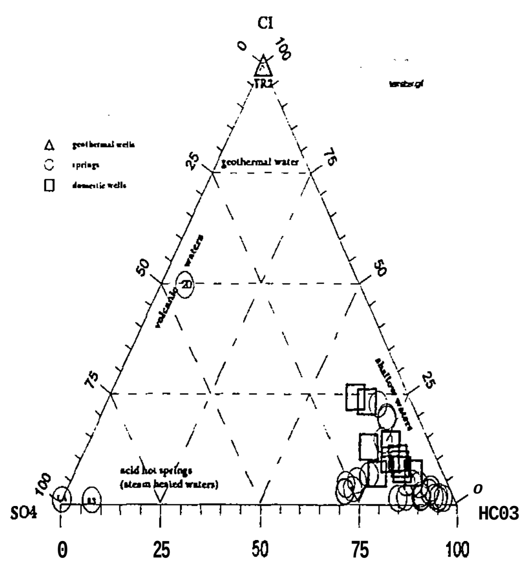

Figure 2. Triangular diagram Cl - HCO, - SO_4

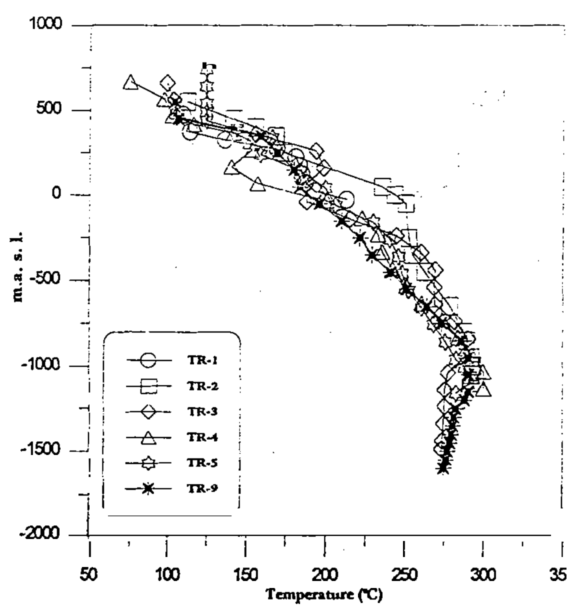

Figure **3.** Relationship of temperature with the depth in geothermal wells.

2.2. Deep geothermal **fluid**

The deep waters of the Berlin geothermal system correspond to the drilled geothermal wells, producing and reinjection, in an approximate area of **6** km^2 .

Figure **3** shows the temperature profiles for the wells TR2, TR3, TR4, TR5 and TR9 according to the records of the dates indicated in the figure.

Well TR-2 presents a maximum measured temperature of **289** "C to a depth of **1700-1800 m. (**- 948, -1048 masl), and presents maximum chloride concentrations of **6238** ppm to **1400** m, **7600** ppm to **1750** m and **6268** ppm to **1900** m of depth (figure **4),** that would constitute the main feed zones to the well The computed deep temperature using the Na-K-Ca geothermometer gives a temperature of **290** "C (see table I).

Well	Depth	Hm	T_{meas}	$T_{Na/K}$	$T_{Na-K-Ca}$	T_{SiO_2}	$T_{Na-K-Mg}$
	m	J/g	°C				
TR-I	1458	997	239	202	200	206	
TR-2	1903	1350	289	292	290	300	
TR-3	2300	1280	296	267	263	262	
TR-5	2083	1370	305	315	327	284	320
TR-9	2300	1300	295	300	291	283	310
TR 10	2350	1085	250	202	200	212	290

Table I. Physical parameters for geothermal wells in Berlin.
Hm: measured enthalpy

For well **TR-3** the maximum measured temperature is **296** (figure **3),** with a maximum of chloride of **5353** ppm to **1900** m. (figure 4). The computed temperatures of Na-K-Ca and silica geothennometers give values of **263** and **262** °C respectively.

Well TR-4 has not flowed to date after multiple efforts by achieving it. It is counted only with temperature and chemical data from the water column.

For the well TR-5, the maximum measured temperature is **295** °C to 1900 m **(** - 1059 masl). The maximum chlorides concentration is found in the same depth with **3798** ppm (figure **4),** in agreement with the zone of reported total losses during the perforation. The computed geothemperatures are of **327 °C** for the Na-K-Ca geothermometer and **284** "C for the silica geothermometer.

Well TR-9 shows the maximum measured temperature value of **295** "C in the depth range of **1600 - 1800** m (-951 and -1151 masl **)**. The maximum chloride concentrations are found at **1700 m** with **4344** ppm and **1900** m with **4078** ppm. The temperatures computed for the Na-K-Ca and silica geothermometers are **291** and **283 °C,** respectively, (table 1).

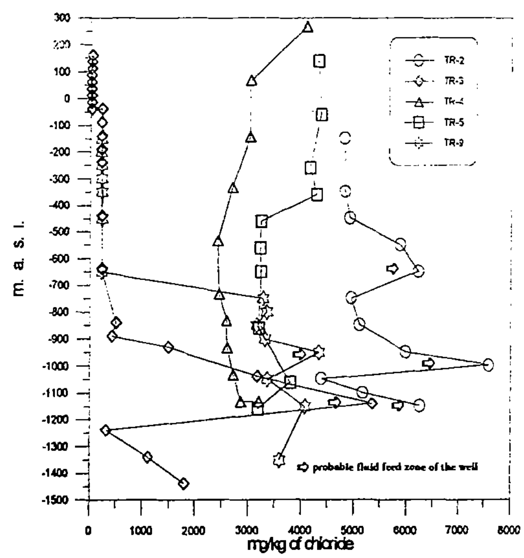

Fig. **4.** Chloride concentration in function of the depht.

Figure 5 shows the enthalpy-chloride diagram. In the graph can be appreciated the possible physical-chemical processes that could be occurring in the geothermal system. If we assume that the fluid that feeds well TR-5 is the most representative of the deep system (primary fluid), the fluid of the wells TR-2, TR-9 is product of a boiling (stem looses) with the consequent chloride concentration and the temperature decrease. The fluid of wells TR-1, TR-4 is product of conductive cooling without the chloride content be mostly affected. The fluid of the well TR-3 presents a chemical composition abnormally concentrated, what would be explained **as** a consequence of boiling of the primary deep geothermal fluid, with a chloride content of approximately 4000 ppm and an enthalpy of 1700 J/g, respectively.

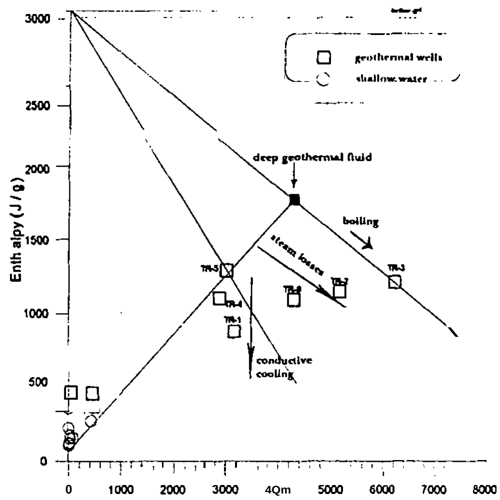

Figure 5. Chloride-enthalpy diagram.

The figure 5 also indicates the mixing trend of geothermal water with shallowf water to produce the fluid of the spring 20, with a 70-80 % of geothermal component and a 20-30 % of superficial component.

3.0 STABLE ISOTOPES

The local meteoric water line was calculated based on the weighted monthly isotopic averages of rainfall data from the Ilopango station, San Salvador, **(IAEA,** 1992), and it is defined by the regression equation of SH = 7.92 * $\delta^{18}O$ + 9.336, with a correlation coefficient r^2 = **0.96** and for n=70 samples (Fig. ***6).***

The location of shallow waters (circles) is near the meteoric water line, according to their chemical-isotopic composition of shallow water. The geothermal wells (squares) show greater $\delta^{18}O$ conteni due to the water-rock interaction in the reservoir. The fluid of the spring F-83 and the Laguna de Alegria **(L.A.)** have suffered a high evaporation, that has concentrated their isotopic composition. The Laguna de Alegria presents an isotopic composition of $\delta^{18}O$ and δ^2H of - 1.42 ‰ and - 12.2 ‰, respectively. The spring F-83 probably is the result of the condensation of the steam that emerges in the zone, since is located about 5 m southward of the fumarole El Tronador.

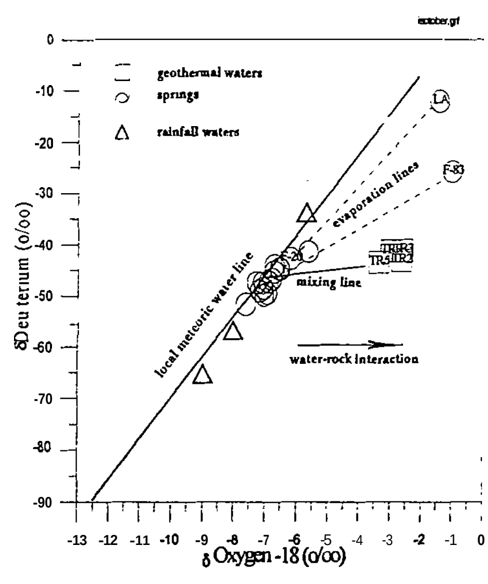

Fig. 6. Meteoric water line curve

The position of the spring F-20 shows a light enrichment in $\delta^{18}O$ and δ^2H with respect to the other springs. It **is** observed that the content of δ^2H of approximately -41 to -43 ‰ is quite similar to that of the geothermal wells, that suggests the posibility of a common origin, **i.e.,** the fluid of the **spring** F-20 is probably product of geothermal water mixed with shallow water, such **as has** been mentioned previously. **The** position of the geothermal wells suggests the steam losses by evaporation and/or boiling of the wells TR-2, **TR-3** and TR-9 suffered fi-om fluid of the well **TR-5,** that produces the isotopic enrichment of the first.

4.0 GAS CHEMISTRY

Table 2 reports the chemical gas composition in mol per cent and the computed temperatures from gas geothermometers. The relative contents of Ar - N_2 - He are plotted in a trianguiar diagram (figure 7). From this graph it is evidence for the gas of Berlin a partial origin from an andesitic magma, that is inferred because of the high ratios of both N_2/Ar and N_2/He. In the diagram it is supposed a pure meteoric origin for argon. Helium is supposed to be originated from mantle (D'AMORE et. a!., 1996).

Well	Date	CO_2	H_2S	H_2	CH,	CO	N_2	Ar	He	T_{SNHG}	T_{CO2}
		concentración in % mol								°C	°C
TR 2	20.06.95	81.9	6.53	0.33	0.0160	0.00019	11.5	0.065	0.002	310	305
TR **5**	12.05.95	90.4	2.77	0.22	0.0124	0.00014	6.6	0.050	0.002	320	310
TR 9	22.06.95	83.9	7.69	0.34	0.0478	0.00077	8.0	0.047	0.002	310	*275*
TR 3	1986	83.3	10.3	1.43	**0.21**		**1.8**			320	

Table II. Gas composition (% mol) and geotemperature values ("C) for Berlin geothermal wells.

The areal distribution of H_2 in mmol/100 mol of steam for fumaroles of the area is shown in figure 9. It indicates that the heat source of the system is located toward the southeast of the city of Berlin, in the area of circular faults which originates the caldera of the ancient volcano of Berlin (Dept. of Exploration, 1991). The concentration of H_2 trends to decrease in a radial shape in the N-NE and **S-SW** direction that is indicative of a flow path in the same direction.

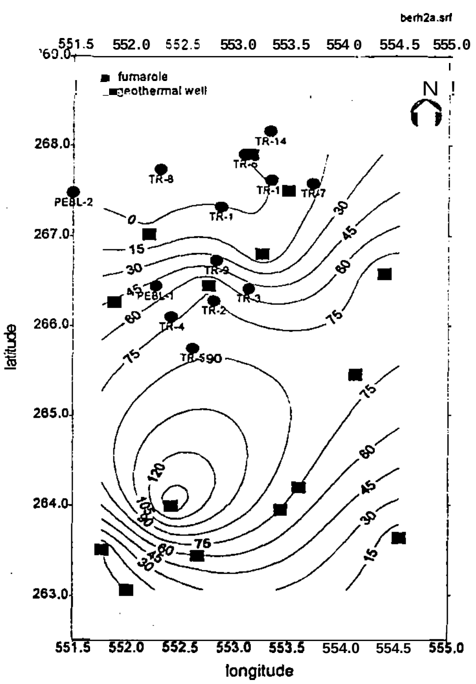

Fig. 9. **Areal distribution of hydrogen concentration in mmol/100 mol of steam**

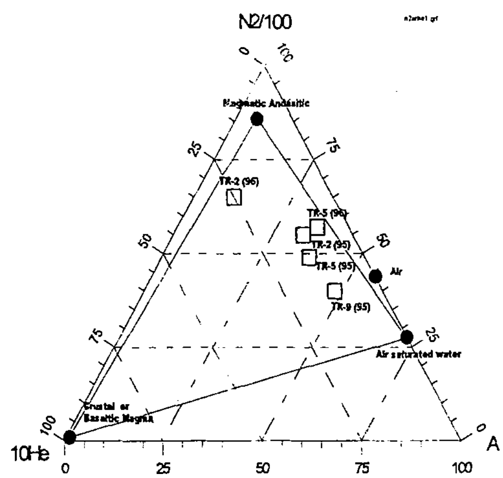

Figure 7. Relative content of Ar-N_2-He for the wells in Berlin field.

5.0 GEOCHEMICAL CONCEPTUAL MODEL

The geochemical evidence of areal distributions of temperature, chlorides **and** the cl-enthalpy diagram show that the main upflow zone of geothermal fluid is located in the southern part of the field. This hot deep geothermal fluid cools while flows northward by processes, predominantly of boiling **and/or** evaporation. The principal vertical flow zone (upflow) is in the surroundings of the well **TR-5** from where the fluid is moved toward the wells TR-2, **TR-9, TR-3,** TR-1. The chloride - enthalpy diagram indicates the fact that the deep fluid that feeds to the well **TR-3** has suffered a steam lost by boiling , this provokes an abnormal concentration in the chemical species, evidenced by the high chlorides concentration (greater than 7,000 ppm). The degassing of the liquid and the consequent steam and gases production, which upon ascending are mixed with an intermediate aquifer in the vecinity of the wells TR-3, TR-2 and TR-9 and produce the sulphate waters in the surroundings of the fumaroles of El Tronador and El Tronadorcito, as shown in figure 10. The mixture of NaCl type waters and sulphate type waters ($SO_4^=$) flow northward to a depth such that it does not permit any further mixing with the shallow waters HCO_3^- type. It is supposed that in the surroundings of the zone of Montañita and Santa Anita, exist some mineralgical stratum with a very poor permeability that does not permit the mixture of the mentioned fluids.

In the banks of the Lempa river, to the NW of the geothermal field, this mixture fluid NaCl-SO_4 arises and mixing slightly with shallow waters, producing the fluid that feeds the spring F-20, which presents a chloride concentration of 400 ppm and *365* ppm in $SO_4^=$, and a temperature of *65* °C.

The heat source the system would be located southward of the geothermal wells zone, in the zone of the circular faults that originated the caldera of the ancient volcano of Berlin. The greater concentration of H_2 is found in this zone, toward the Southeast of the city of Berlin, with clear trends to reduce in radial form in the N-NE and S-SW direction from this effusion center, that is indicative of main flowpath in the system.

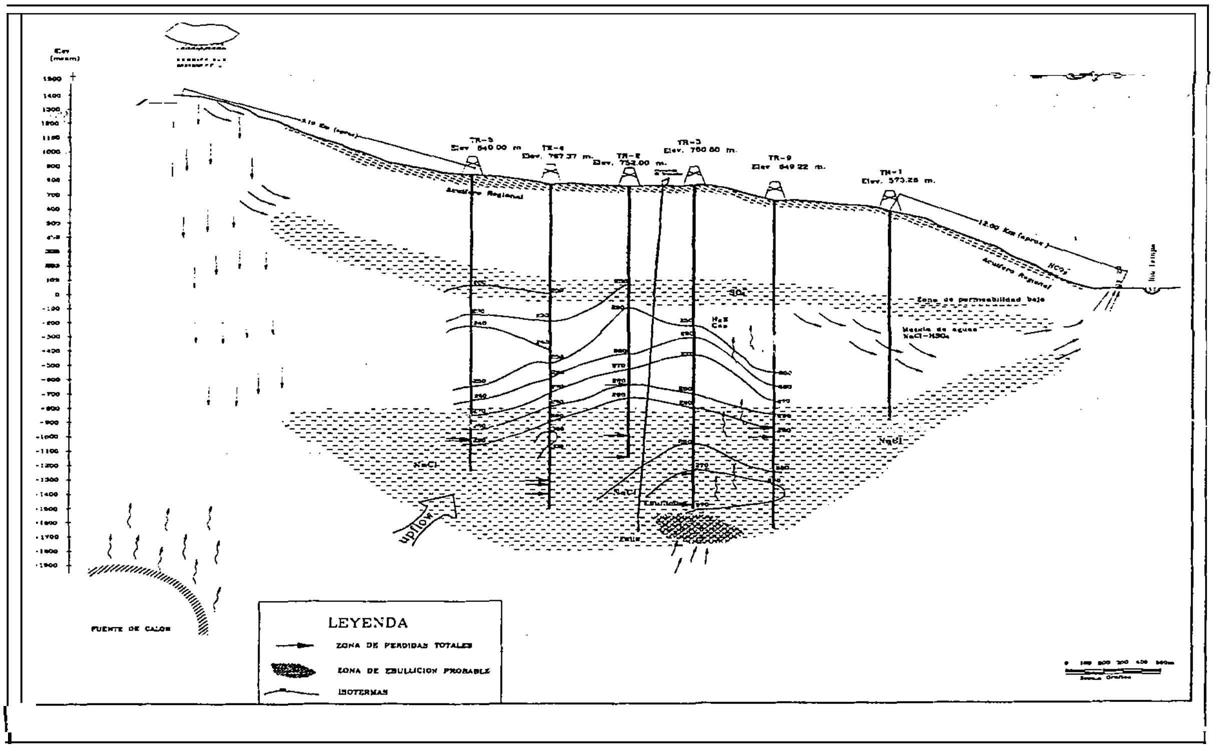

Figure 10. Chemical conceptual model for Berlin geothermal system.

6.0 CONCLUSIONS.

The fluid that feeds the geothermal reservoir of Berlin originates in the South **and** enters to the system from the botton (vertical fluid ascent) in the surroundings of the well **TR-5** and then flows with N-NW direction. In this flowpath, the fluid loses heat by processes predominantly **of** boiling andor evaporation producing the fluid that feeds the wells **TR-2,** TR-3, **TR-9,** and TR-I.

In agreement with the chloride-enthalpy mixing diagram, exists boiling in the fluid that feeds the well TR-3 (boiled primary fluid), that could explain the abnormal high chemical content of the well to reservoir conditions. As a product of the boiling in the fluid in the well TR-3, is produced steam and gases, those which upon ascending are mixed with an intermediate aquifer in which the sulfidric gas is diluted providing the composition predominantly sulphate.

The mixture of NaCl type waters with the sulphate type waters, flows Northward to a depth such that it does not permit any further mixing with shallow waters. Probably in the surroundings of the hamlets Montaiiita and Santa Anita exist a geological barrier with a very poor permeability that does not permit the fluids ascent and mix with the shalow fluids.

In agreement to the present study, is believed that mixture of geothermal-sulphates waters emerges toward the North where is mixed slightly with sallow waters, giving rise to the flow that feeds the spring F-20, which presents a chlorides concentration of 400 ppm and of sulfates of 365ppm, and a temperature of 65 °C.

The areal distribution of hydrogen gas fro the fumaroles indicates that the greater concentration of this gas (associated with the heat source that produces it), is located Southward of the geothermal wells zone. This indicates that the principal source of heat of the system is located in the zone of the circular faults that originates the caldera of the ancient volcano of Berlin.

7.0 REFERENCES

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