

CONCEPTUAL MODEL OF THE BERLIN GEOTHERMAL FIELD, EL SALVADOR

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Abstract

A correlation between geological, geovulcanological, geochemical, hydrological and geophysical studies, drilling results and well measurements are interpreted in this report.

The heat source of the Berlin geothermal system is associated with a chamber magma, located under two concentric calderas. The outer caldera is open to the North. Two aquifers and their seal cap have been revealed. The first one is a 300°C reservoir, NaCl composition. The second one 200°C calls intermediate aquifer. Hydrothermal alteration agrees geothermometry and temperature measurements. Natural recharge is mainly through the calderas. An infiltration of 25 m³/s exists into the system. The upflow is through the borders of the inner caldera. The system is open to the NNW flowing along a local graben. The outflow probably has a hydraulic barrier to the North. It is a mixing of the NaCl hot reservoir, intermediate aquifer and meteoric water: Discharge zone is not complete understanding.

1.0 INTRODUCTION

The Berlin Geothermal field is located 100 Km to the East of San Salvador, the Capital city of El Salvador, Central America (Fig. 1). It has been object of study since the 1960's. In 1968 was drilled the first well TR-1. In 1977 CEL carried out gravity and resistivity surveys. During the following 4 years wells TR-2,3,4,5,9 were drilled. In the early 1990's CEL installed 2 well head units (5 MWe each) and drilled wells TR-8,10,14 to reinject residual fluids into the system. During 1994 Geothermal Energy New Zealand (GENZL) carried out a geovulcanological study, analyses of geochemical data and MT survey in Berlin. From October 1994 to July 1995, CEL did both gravity and Schlumberger resistivity DC surveys. Isotope and hidrological results were incorporated last year.

The system is still considered to be as a quasi-natural stage. The field is about 6 Km (WE) wide and 10 Km (NS) long. The Southern edge of the system is located at the two concentric calderas of Berlin. The system is 15 Km² at depth and its thermal potential has been calculated to be at least

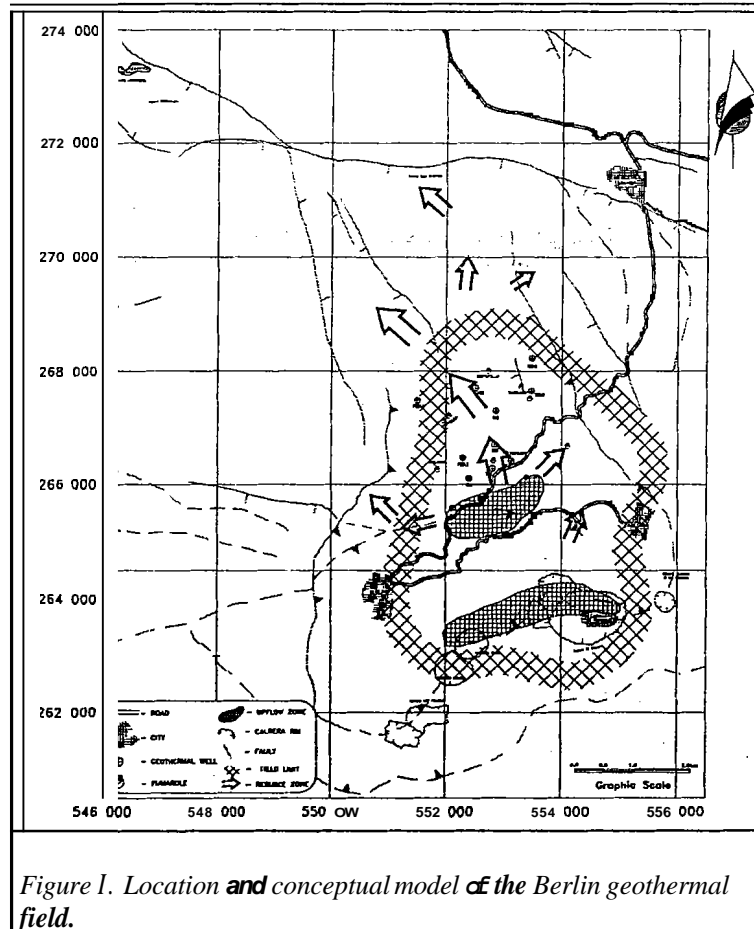


Figure 1. Location and conceptual model of the Berlin geothermal field.

100 MW. The current bore field starts 2 Km to the North from the inner caldera and extends about 3 Km to the North. Current exploitation wells are TR-2 and TR-9. 8 MW total generation has been producing since 1992. Residual water is complete reinjected in the wells TR-1, TR-8, TR-10 or TR-14. A first development of 55 MW in a condensation plant will start building in 1997. New reinjection and production wells drilling will begin on March 1997. Large scale generation is estimated to start in 1998.

Based on the results of the conceptual model well sites were confirmed last year. Designs of directional and vertical well are actually being prepared. Five directional production wells will drill from the wells TR-4, TR-5 and TR-3. Three vertical and 2 directional reinjection wells will drill 2.5 Km to the NW from the current reinjection zone. A maximum real depth of 2.5 Km per well is estimated to be drilled.

By using all the available information, drilling results and well measurements, CEL wrote the conceptual model of the Berlin geothermal system. This paper is a summary of the conceptual model and will focus it.

2.0 GEOLOGY

The andesite-basalt volcano of the Berlin geothermal field is located in the southern fault system of the Central American graben with WE direction (Fig. 1). Berlin area is a weakness zone created by the intersection of that graben with its conjugated fault systems NW-SE and NE-SW striking. The graben is related to the subduction process of the oceanic plate "Cocos" under the continental plate "Caribbean". Fusion phenomena of the continental plate have produced andesite magma. This has risen and accumulated in the weakness zones of the crust. A magmatic chamber has been generated in the South flank of the Berlin field (Fig 1) to a depth approximated among 6 and 8 Km (E.I.C, 1994).

The volcano-tectonic activity took place during the Pliocene epoch with the formation of the Central American graben and the conjugated fault system. (Table I) The volcano of Berlin emerged in the southern part of the graben. It occurred more than 1.4 millions of years ago. In the final activities of the Berlin volcano (0.1 Ma ago), eruptions of large quantities of ignimbrite products gave rise to the collapse of the volcano and formation of the caldera of Berlin. The geometry of this caldera indicates that the collapse was given simultaneously to the activity of the NW-SE fault systems. This caldera is open to the North as a result of the creation of the graben of Berlin, NW-SE direction.

Table I. Characteristics of the Berlin Geothermal System.

BERLIN GEOTHERMAL FIELD										
Elev. (masl)	SYSTEM STRUCTURES	LITHOSTRATIGRAPHY UNITS	LITHOLOGY DESCRIPTION	MAIN VOLCANOE TECTONIC EVENTS	CRONOLOGY	HYDROTHERMAL FACIES	GRAVITY DENSITY gr/cm ³	RESISTIVITY Ohm-m	PERMEABILITY (md)	CHEMICAL FLUIDS
1000										
800										
600										
400										
200										
0.0										
-200										
-400										
-600										
-800										
-1000										
-1200										
-1400										
-1600										
-1800										
-2000										

Eruptive center formations and volcanic product emissions continued in the caldera. An inner and smaller caldera, called Blanca Rosa (means White Rose), was formed inside the outer caldera 75000 or more years ago. The

volume of fall and flow of dacite pyroclastic support that the Blanca Rosa caldera exists there. A subsequent activity gave origin to the actual Quaternary volcanic complex of the Berlin. A phreatomagmatic eruption, called Hoyón crater, occurred 700 years ago. The volcanic eruptions have been classified in 5 unit formations (Table I)

3.0 HEAT SOURCE

The volcanic activity time of more than 1 M years indicates the existence of an active magmatic chamber that generates the heat of the system (Fig. 3). The magnetotelluric study (GENZL,1994) identified a deep conductive zone in the proximity to the magmatic chamber. Additionally, the relative contents of nitrogen gases, helium and argon indicate that the origin most probable of the gases is in part magmatic and in part meteoric. The interpretation of the results confirms that gas originating from a deep source is originated mainly by the interaction gas-rock-water related to a andesite environment (D'Amore et all, 1996). The heat source is located to the South of the production geothermal wells. This is evidenced by a greater concentration of hydrogen in this zone (Tenorio, 1996). Resistivity and gravity data indicate that the system is found confined to both caldera and graben of Berlin (Handal,Quezada and Santos, 1995).The system is opened toward to the NW and its frontier South corresponds to the ring faults of the calderic border.

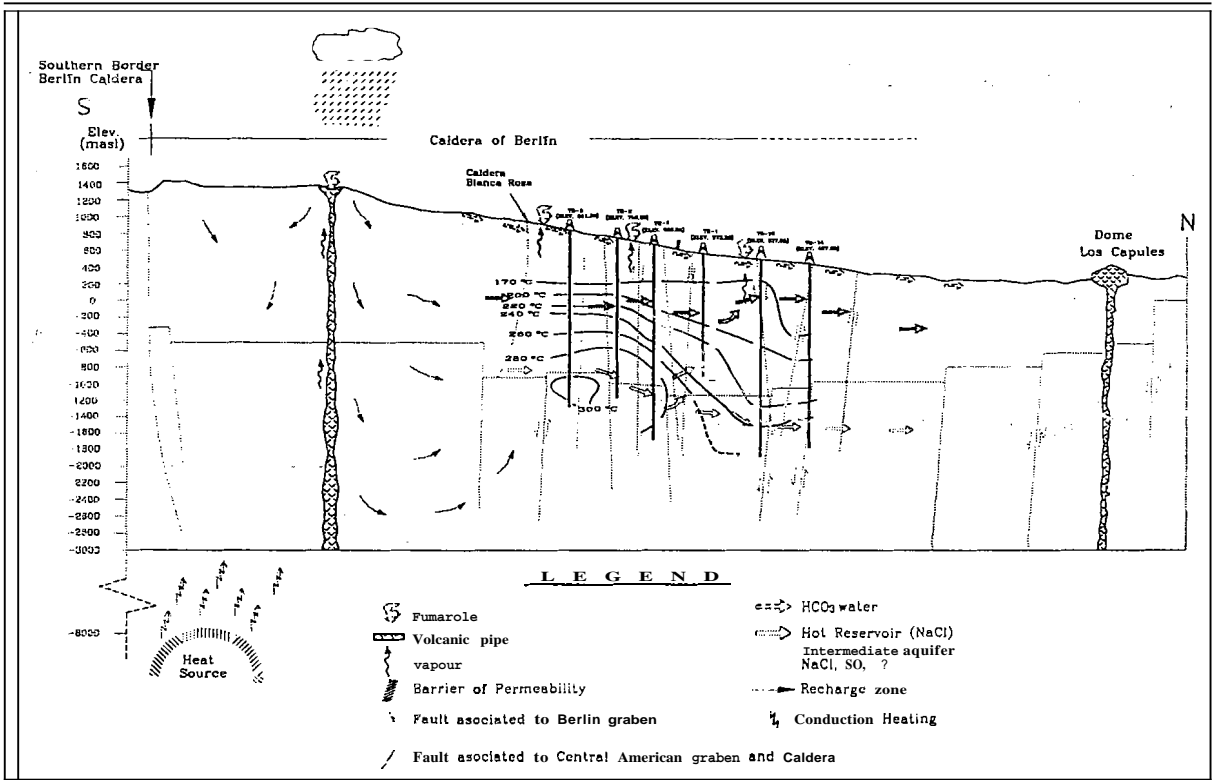


Figure 3. Conceptual Model of the Berlin geothermal field. Profile from South (S) to the North (N)

4.0. TWO GEOTHERMAL RESERVOIRS.

4.0.1. DEEP HOT RESERVOIR

Drilling results have revealed a deep reservoir and an intermediate aquifer (Fig 3 and Table I). The top of the deep reservoir is among -800 and -1000 masl. Its thickness has been estimate to be 1000 m. It is located in the lithostratigraphy Unit V, constituted by a monotonous lavas sequence predominantly andesite-basalt that are interrelated in surface with the ancient lavas of the Berlin volcano and/ or eventually with the basement of the Balsamo formation (Aguilar et all, 1996). Considering thermodynamic variable measures, it has been determined that the reservoir is of the dominant liquid phase. In the production zone (wells TR-2,3,4,5,9) 300°C temperature has been measured. The reservoir presents a cooling northward, since the temperatures measured in the reinjection wells TR-1,8,10,14 are in the order of 250°C. Chemical data evidence a chloride-sodium composition of the reservoir. Isotopic result of oxygen 18 and deuterium show the pattern fluid is represented by the fluid in or near the well TR-5. Wells TR-2,3,9 have difference isotopic composition that is probably caused by the occurrence of boiling in the fluids feeding the natural reservoir (Tenorio, 1996). Permeability is secondary and it is 100 mD in the production zone. As can seen in Table I, the permeability is smaller in the reinjection zone (CEL, 1996). Hydrothermal alteration is dominated by epidote mineral or prophyllitic face. The stable temperature in this face agrees with measurement and geothermometry temperatures (Table I and Fig. 2). The reservoir was not defined by the electrical resistivity methods. It was masked by a shallow conductive cap (CEL, 1996). Nevertheless quantitative gravity 2.5D modellings indicate the stratum (density 2.45 g/cm³) of the reservoir is deepened gradually northward (Santos, 1996).

4.0.2. INTERMEDIATE RESERVOIR

The top of the intermediate reservoir or aquifer is among 250 and -50 masl (Fig. 3 and Table I). it is around 300 m thick and located in the lithostratigraphy Units I and II (Table I). It is constituted by interlayering of andesite and andesite-basalt lavas, levels of lithic tuff levels. Also, it consists of andesite pyroclastic and ignimbrite, that are interrelated on the surface with grey ignimbrite erupted by the Berlin caldera (Table I). From a thermodynamic point of view, it has been determined that this intermediate aquifer is liquid dominant. Its temperature is 150°C-200°C range and was identified in the production zone located in the South. The wells of the North zone have presented thermal anomalies that insinuate the presence of the intermediate aquifer. Most of the wells have been completed with blind pipeline, therefore there is not information on the chemistry composition of this aquifer. The permeability has solely been indicated by total circulation losses in the South and partial losses in the North. Hydrothermal alteration is of the argillytic-phillytic face (clay and chlorite minerals) that agrees with the temperatures measured (Table I). This aquifer was indicated by a great electrical resistivity contrast between a conductive stratum and an under resistance layer (CEL, 1996). These electrical differences are caused by the development of the phillytic-argillytic face under a shallow clay minerals zone (argillite zone). Northward of the well TR-10 the constrast is notably reduced suggesting the presence of a hydraulic barrier. Northward, the Units I and II are denser than the South as a result of self-sealing and cooling phenomena (handal & Quezada, 1995).

5.0 SEAL CAPS

By using static temperature profiles in wells, hydrothermal alteration faces and resistivity data, the seal cap of both the hot reservoir and the intermediate aquifer have been determined (Table I).

Under the intermediate aquifer is not revealed a conductive thermal regime that permits to define a seal cap for the hot reservoir. The temperature gradually increases until the top of the reservoir, what is interpreted as resulting of a certain degree of vertical permeability. There is not complete isolation between both aquifers. However, it exists a seal cap that corresponds to a fine tuff in the Unit V that has been altered to clay and chlorite minerals (Table I) (Aguilar, 1996). Any geophysical method evidence this seal cap.

A high gradient zone of temperature (200 m thick) has been identified between 500-400 masl and 200 masl. This conductive thermal regime reveals decreasing in the permeability. This zone constitutes the seal cap of the intermediate aquifer. It is in the Unit I that have been intensely altered developing clay and chlorite minerals (Aguilar, 1996). This cap is found in direct correspondence with a shallow conductive layer identified by the

resistivity studies. Gravity interpretations show a denser cap that is associated with the seal cap of the intermediate aquifer. Hydrothermal alteration has partially reduced the vertical permeability.

6.0. CIRCULATION OF THE THERMAL FLUIDS.

Natural recharge is located in the high parts of the volcanic complex of Berlin. Meteoric water is going down into the system through the ring faults of the caldera. An equivalent infiltration of $25\text{m}^3/\text{s}$ has been estimated (Castellanos, 1996). According to the position of the well TR-5 in the Entalphy-Cl diagram, it is assumed that its fluid inflow is the most representative of the reservoir (Tenorio, 1996). Geothermometry data indicate that the highest temperatures in the reservoir are reached southward of this well. This zone is considered to be the upflow of the system (Table I, figs. 1 and 2). Hot fluid rising to the South of the well TR-5 interprets as that occurs probably through the faults of the caldera Blanca Rosa.

Measured and geothermometry temperature isocontours and entalpy-Cl diagrams indicate that the temperature decrease to the NNW. This is confirmed by the entalphy-Cl diagram. These results indicate the existence of a lateral flow controlled by the faults of the Berlin graben. Surficial discharge of the reservoirs is not still perfectly recognized. However the entalphy-Cl diagram reveals a possible mixing to produce a spring located at the NW, among 4 and 6 Km apart (CEL, 1996).

The lateral flow of the intermediate aquifer result substantially from data in wells, geophysical and correlation with the tectonic. There is not chemical sample to indicate the fluid composition. Resistivity isocontours reveal the lateral movement of the fluid. Those isocontours are extended with N direction from the upflow zone. It is propagated through out the interface between the shallow conductive layer and the underlying resistance cap. When it finds the hydraulic barrier, near the current reinjection zone, probably bends toward NW until to emerge at 4 or 6 Km afar. High gravity anomaly along the graben reflects the path of this aquifer.

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