CONCEPTUAL GEOPHYSICAL MODEL OF THE BERLIN GEOTHERMAL FIELD, EL SALVADOR

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ABSTRACT

The results of the geophysical studies carried out in the Berlin geothermal field delineate an extensive geothermal field of $15 Km^2$ *at depth. This extends from the south limits of the Berlin caldera and gradually narrowing towards the Northern part of the field.*

Two probable upjlow zones have been determined by MT and direct current (VES). The first one is located near to the south limit of the Berlin caldera. The second one, which is located near to TR-5 well, is supported by highest temperatures and lowest resistivities measurements.

A good correlation between the results of resistivities survey and borehole data have been observed at the southern part of the wellfield. This suggests an equilibrium behveen the hydrothermal alteration and the temperature, as well as a cooling process in the northern part of the field.

A qualitative and 2.5D quantitative interpretations of the gravity data, yield some evidence about an asymmetrical graben in the Berlin geothermal field. The results do not show any evidence supporting an edge North of the Berlin caldera.

1.0 INTRODUCTION

El Salvador is located on southern coast of Central America, where Cocos plate is subducting underneath the Caribbean plate forming a E-W tectonic graben. On the southern margin of this graben lies the Quaternary volcanic chain. Seven high temperature geothermal fields (280-320°C) have been identified lying on northern flanks of this volcanic chain .Berlin geothermal field is situated 100 km east of San Salvador (capital city), associated with the Tecapa volcanic group and the Berlín caldera of Pleistocene age (Pullinger,1995).

Berlin geothermal field have been under exploration since 60's decade. The first DC resistivity survey was conducted by the Comisión Ejecutiva Del Rio Lempa (CEL) in 1977. Between 1994 and 1995 several geophysical studies were carried out for different companies: A magnetotelluric survey conducted by Geothermal Energy New Zealand, GENZEL (march-june/94).The second DC resistivity survey as well as a gravity study were done by CEL.
From the results of these geothermal exploration, a conceptual geophysical model is presented in this work.

2.0 BERLIN GEOTHERMAL FIELD

2.1 Geological and structural setting

The subduction of the Cocos Plate under Caribbean Plate has formed a tectonic graben that runs E-W through El Salvador. Berlin volcano appears to be centred where the regional NW treading fault system intersects the southern margin of the E-W trending faults system formating the Berlin graben of 5 km wide. The forming of one of large basaltic andesite composite cone during the last 1-2 millions years which was interrupted twice by the last explosive andesite eruption of the black and grey ignibrites. These eruption were accompanied for a collapse of the upper part of the central cone, controlled partially by the previously existing NW treading faults (GENZL, 1995).

the conjugated NE faults transport the geothermal fluid from the upflow zone close to the young craters towards the wellfield. This fluid is discharge at several hot spring close to San Simon and Lempa rivers, showed in the structural geological map of the Figure 1 (Pullinger,1995)

2.1 Alteration mineralogy

The mineralogical facies of Berlin Geothermal Field are defined based on the empirical relation between the rok formation temperatures measured from the wells and the alteration temperature of the secondary minerals. The mineralogical facies as a function of the temperatures from Berlin geothermal field are described by Pullinger and Barrios in the report "Evaluación de informacion geocientifica de pozos TR-14 Y TR-8" and being summarized the table I. The range of temperature specified in this table, are referred to the stabilization temperatures of the secondary minerals and the depth range shows the depth of identification of the minerals in the north and southern part of the geothermal field respectively. The thickness and the lower limit of prophilithic facies has not been identified.

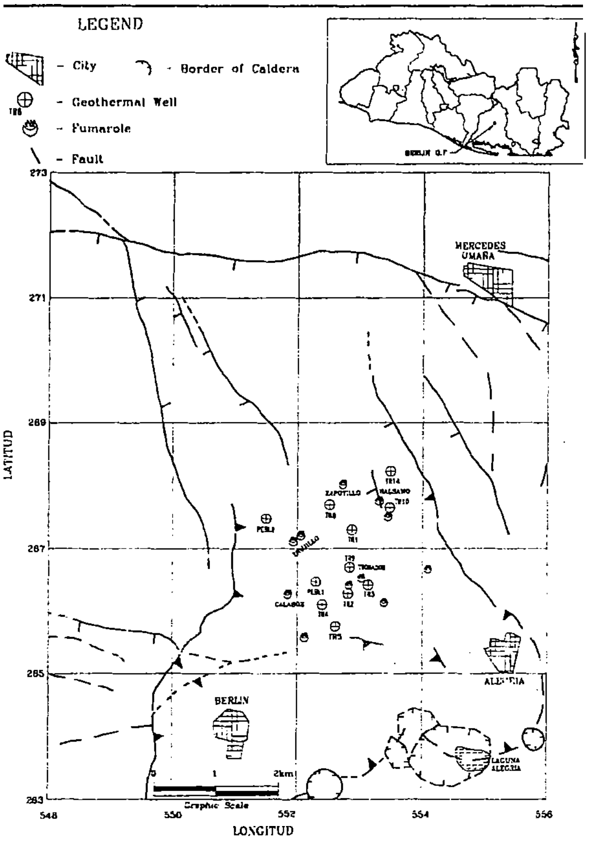


Fig. 1: LOCATIOS MAP. BERLIN GEOTHERMAL FIELD

TABLE I: Classification of mineralogical facies of Berlin geothermal field

Facie	Characteristic minerals	Temperature range ("C)	Depth range (m a.s.l)	Average Thickness (m)
Argillic	Clay mineral: zeolite,and smectite type.	50 -150	500 to 150	400
Phyllic-argillic	Clay mineral type chloritic: Zeolite, Quartz, Calcite	150 -180	100 to -100	400
Phyllic	Diminution clay mineral and traces of chlorite	180 - 200	-400 to -700	600
Phyllic-Prophylithic	Chlorite group (type pennite) and epidote traces	200 -230	-950 to -1200	300
Prophylithic	Epidote	230 - 250	- 1200 to ?	?

3.0 RESISTIVITY SURVEY

3.1 Magnetotelluric Survey

A high quality Magnetotelluric survey was carried out by GENZL in the Berlin Gerthermal Field, a total of 57 soundings were made over an approximate area of 80^2 Km, centered on the borefield. Of these, 43 were AMT/MT sounding stations. The frequency utilized ranging between 10,000 and 0.001 Hz.

3.1.1 One dimensional interpretation

Bostick Resitivity Interpretatión: The one dimensional interpretation was done by GENZEL using the GDmanager Integrated Data Manager System. For this work GENZEL used the Bostick transformation of the effective resistivity (the geometric average of the two principal apparent resistivities).

The outlined the conductive layer within the Graben southward through the Caldera baunded by apparent extension of the graben faults (Anderson at, 1994). This conductive anomaly is being interpreted as argillic alteration above an extensive zone of high-temperature geothermal water. The general shape of this anomaly suggests an outflow zone toward the northern part of the geothermal field.

At the reservoir level (-1000 m.a.s.l), an extensive low resistivity area is delineate at the south of the wellfield, bounded by the caldera, suggesting a possible upflow zone in this area. Higher resistivities values are observed in the wellfied zone, possibly due a reduction in the porosity.

3.1.2 Layered model

All model showed a basic three layer structure:

A conductive layer: Located within the graben and the Berlin caldera. The highest elevation is observed on the southern caldera boundary. The resistivity values of this layer range from 1 to 30Ω-M. The lower resistivity values are confined within the mapped Berlin Caldera. This conductive layer is being interpreted as the argillic alteration zone, and does represents temperatures ranging from 100° to 180°C .

Resistivty layer below conductive cap: this layer is believed represent: the high temperature reservoir of Berlin geothermal system . The Figure **2** shows the level of the top for this layer. The pattern of this map indicate a outflow down to the center of the local graben. The resistivity values of this cap presents values 730" R-m in the borefiel area, while within the caldera zone, the measured resistivity values are less than 15 Ω-m. This is possible due a reduction in the porosity within the actual wellfield zone. This resistivity values are similar to those proposed for typical propyllitic alteration expected within the reservoir (Johnstone et al, 1992)

A very deep conductive layer: This cap have been very poorly defined, principally because at this depth (>2kn) the MT sounding are strongly affected by three dimensional effect. This layer is interpreted as a remant of the decite magma **body,** associated with the ignibrite eruption (100,00 years back) on the caldera formation (Anderson at al, 1994) .

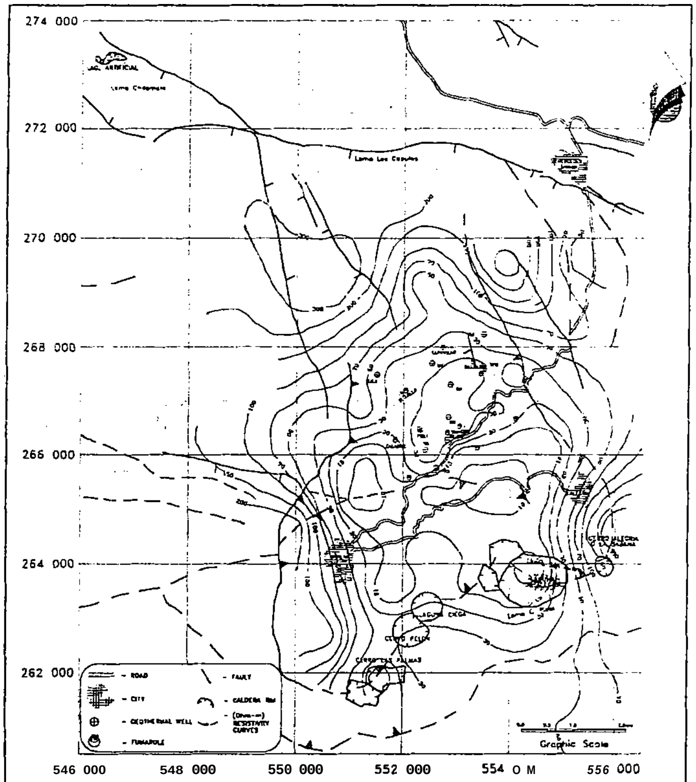


Fig. No.2:
ELEVATION OF RESISTIVITY LEYER BELOW CONDUCTIVE CAP
(Según CENZL. 1994)
BERLIN GEOTHERMAL FIELD

3.2 DC resistivity survey, Schlumberger array.

A total of 41 station were measured with maximum AB/2 ranging from 1000 to 2000 mt. The sounding are distributed in a regular grid with an average separation **of** 1 Km, crossing the main geothermal area. The main result from this resistivity survey are presented in this section.

The equipment used were transmitters model TSQ-3 and **TSQ-4** and one channel analogical receivers models IPR-8 and IPR-10 of the SCINTREX

3.2.1 Iso resistivity maps

In general the isoresitivity maps show an elongated low resistivity anomaly within the caldera and extending to NNW into the NNW-SSE tending the fissure swarm indicating an outflow zone along this faults system. The size of this anomaly increase with the depth indicating an extensive geothermal system at depth. The main active area seems to be at the intersection between the NNW-SSE tending fissure swarm and the faults associated with the caldera collapse (caldera faults).

The high resistivity core below the low resistivity tending in NE-SW, at deeper levels, the area covered by this anomaly increase iso-resistiviy map changing the tendency along to the younger NNW-SSE faults system, suggesting that these system of faults play an important role in the transportation of the geothermal fluids, i.e. an outflow zone. . At -250 m.a.s.l the this anomaly delineate a geothermal field >12 km^2 based on the low resisivity anomalies (Santos, 1995).

The elevation of the top of low resistivity anomaly layer (no shown), as well as the top of the high resistivity core suggest an upflow zone in the southern part within the caldera limits, Which is also supported by the concentration of the higher temperatures, and very low resistivities values in this area.

3.2.2 Layer interpretation

A high resistivity layer at the surface outside the main active geothermal area, associated with the unaltered near-surface rocks above the ground water levels.

A low resistivity (<I 0 Q-m) reflecting the smectite-zeolite alteration zone (argillic-phyllic facies) caused by high porosity, high temperature and ionic conduction in high altered rocks.

A high resistivity core below low resistivity cap caused by change in the electrical conduction mechanism, and by the a decreasing in the porosity due the change in the mineralization from clay minerals to chlorite and epidote group minerals which fill the pores (Figure 3).

A relatively low resistivity layer (12-25 Ω-m) flanking the resistivity anomaly interpreted as a possible cooling area because of a convective recharge (Georgsson et al,1993) or may reflect the typical regional values for the volcanic zones (Flovenz et al, 1985).

4.0 CORRELATIONS WITH THE BOROHOLE DATA

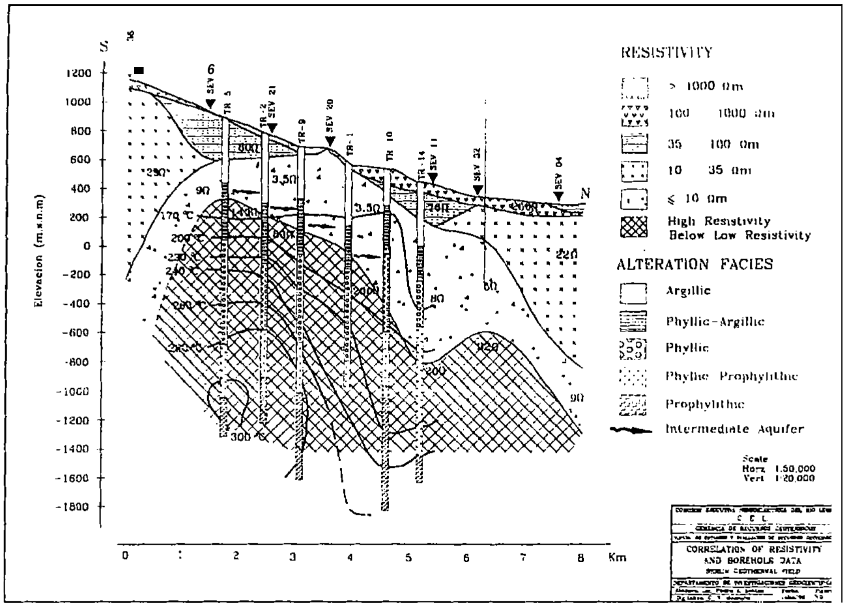
A resistivity survey of a high-temperature field reflects the thermal alteration of the field, hence the temperature, providing there is an equilibrium between the thermal alteration and the temperature.

In order to compare the result of the resistivity survey to the borohole data, the geothermal wells TR-5, TR-2, TR-9 and TR-14 have been projected onto the north-south cross section. (Figure **3).**

4.1 Thermal alteration alteration and resistivity in Berlin geothermal field

The alteration zones in Berlin geothermal field **was** described in the chapter **2.3.** The argillic zone consist of zeolites and smectites (clay minerals) with the interface conduction **as** a dominant conduction mechanism. the Argillic zone would correspond to the low resistivity cap with resistivity values below 10 Ω-m.

The Phyllic-Argillic zone is a mixed layered clay zone and in underlying Phyllic-zone chlorite starts to appear and the clay mineral disappear.



The high resistivity core observed in the resistivity survey appear within the Phyllic-Argillic zone, suggesting there is a change in the conduction mechanism. As stated before, chlorite is a resistive minerals appearing in the Phyllic-zone. another resistive mineral is sericite, a clay mineral also appearing in the Phyllic-zone, sometimes at a higher elevation than the chlorite (IIE, 1992), it therefore concluded that the increase in the resistivity occurs in the intermediate zone (Phyllic-Argillic) between the high conductive Argillic zone(smectite and zeolite) and the resistive Phyllic-zone (chlorite and sericiles). This correlation between the resistivity and alteration in the Berlin geothermal field appear in the southern part of the wellfield. The different picture of well TR-14 suggest a cooling process is happening toward the northern part of the field.

5.0 GRAVITY SURVEY, CEL 1995

In order to provide elements that contribute to define the local graben structure as well as the north edge of the Berlin caldera, CEL carried out a gravity survey from November/94 to June/95. A total 233 gravity station were measured over an approximate area of 77 km^2.

5.1 Qualitative interpretation

The map of the Bouguer residual anomaly (no shown), delineate very well the regional structural framework of the Berlin geothermal field. Other important aspects from this map are:

The contrast observed between the negative anomalies gradients in the west (- 4 mgl/km) as well as the east (1.0 - 1.5mgal/km), suggest the presence of an asymmetrical caldera structure.

The positive anomaly zone (11), confined with in the graben and caldera limits, is interpreted as a sunk block dense due the minerals deposit by the seepage of geothermal fluids through the rock, which is governed by the tectonic pattern.

5.2 Quantitative interpretation, model 2.5 D

The 2.5 dimensional modeling interpretation of the gravity data was accomplished on the residual anomalies through the "MAGIX PLUS program. This calculate a synthetic curve of residual anomalies of gravity based from a initial mode given for the interpreter.

with an average thickness of 250 m. It is constituted by andesites lava unaltered.

Stratum **2:** Constituted by tuffs with intercalated of andestes lava. The

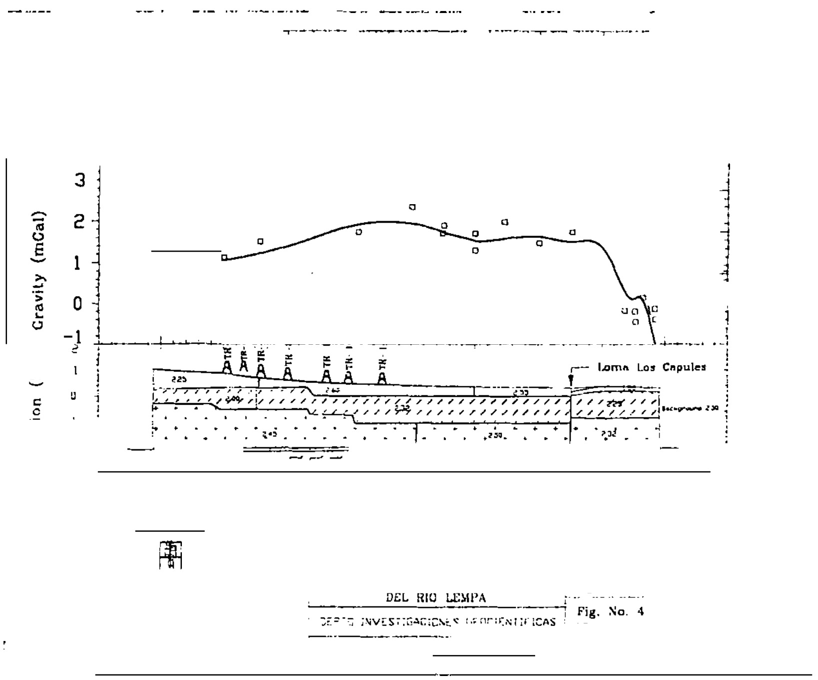
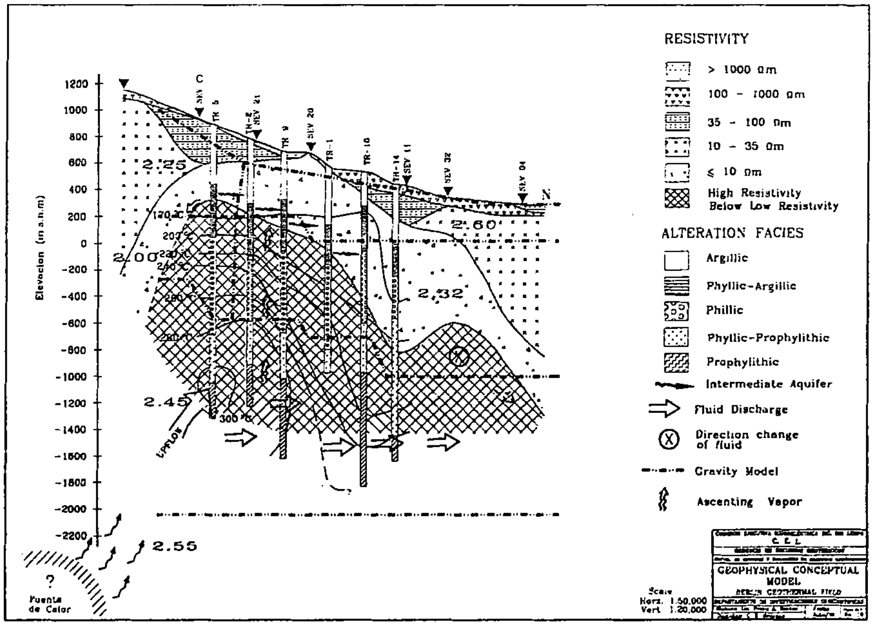


Fig. No. 4

Stratum **4:** Underlie the previous strata, considered **as** the basement, with a density range 2.50 2.55 g/cm3. The lithology correspond to the Balsamo formation constituted by basaltic lava.

6.0 CONCEPTUAL GEOPHYSICAL MODEL OF THE GEOTHERMAL FIELD OF BERLIN.



A conceptual model is a simplified graphic representation of a complex system. The quality of a conceptual model is evaluated- in function of its ability for the predicting, leading to **a** successful geothermal wells location.

From the results of gravity, MT and DC resistivity survey, an conceptual geophysical model have been buitl (Figures 5 and *6).*

The main upflow zone is located within the caldera, near to TR-5 geothermal well, which is supported by the highest temperatures and the lower resistivity values. Other upflow located on the extreme south of the Berlin caldera, on the Tecapa-Berlin volcanic complex.

The outflow zone into the north-northwesterly fissure swarm is suggested by the trending resistivity anomaly shown in iso-resistivity map.

An lateral deep feed zone in inferred from the inversion phenomenon observed in temperature logs of the geothermal wells.

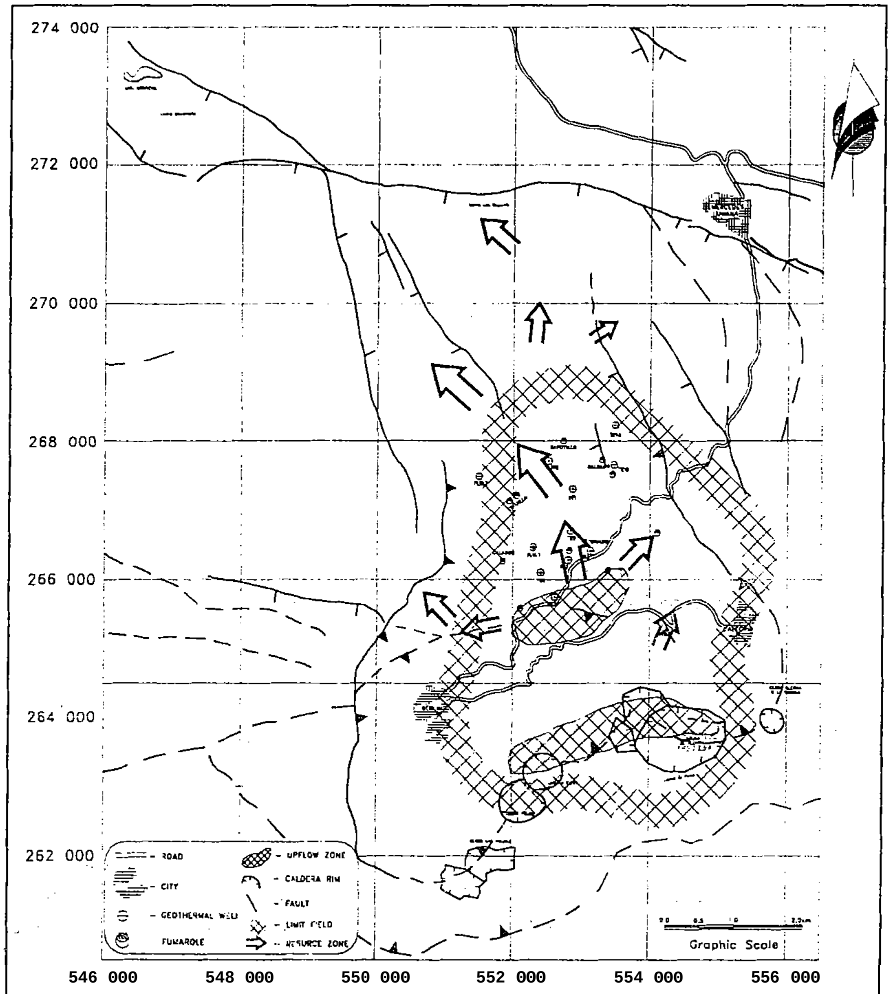


Fig. No.6:

CONCEPTUAL MODEL

BERLIN GEOTHERMAL FIELD

DEPTO INVESTIGACIONES GEOCIENTIFICAS

The source of heat of the geothermal system of Berlin has not been determined by the geophysical studies, except for a deep conductive body suggested by the MT survey. Nevertheless, it is believed that the remaining heat of the magmatic chamber of the Berlin caldera, as well as the magmatic chambers of the volcanoes post - caldera is the heat source for the Berlin geothermal system (Pullinger & Barrios, **1994).**

The Figure *6* shows the outflow from the system *ai-e* shwon by arrows, with ihe width proportional tc the importance of the flow.

The reservoir boundary is shown with a hatched pattern., covering an approximate area of 15 km^2, being extended from the south limits of the boiler, being reduced gradually toward the extreme north of the field, close to TR-**14.**

7.0 CONCLUSIONS

From the results of the Gravity MT and DC resistivity survey is estimated a geothermal reservoir covering an approximated area of 15 km^2, being extended from the south limits of the caldera, being reduced gradually toward the extreme north of the field.

Two upflow zone have been determinated within the Berlin caldera **rim:** The first one close to TR-5, supported by the highest temperatures, highest elevation of the high-resistivity core, and lowest resistivity values in the low resistivity cap. The second one located in the extreme south of the caldera on the Berlin-Tecapa volcanic group.

A good correlation is seen between the resistivity survey, the thermal alteration ad formation temperature derived from temperature logs in the southern part of the wellfied. This support the upflow close to TR-5.

The outflow zone into the north-northwesterly fissure swarm **is** suggested by the trending resistivity anomaly shown in iso-resistivity map.

An lateral deep feed zone in inferred from the inversion phenomenon observed in temperature **logs** of the geothermal wells.

There is an indication of a cooling area in the northern part of the production zone, near to TR-14. This is supported by the temperature logs and the resistivity survey.

The qualitative interpretation of the gravity data lead to define the regional structural framework of the Berlin geothermal field. The quantitative analysis of the data does not evidence the north edge **of** the caldera.

7.0 REFERENCES

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