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LaGeo S.A. de C.V.

CONCEPTUAL MODELS FOR THE BERLIN GEOTHERMAL FIELD, CASE HISTORY

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ABSTRACT

The conceptual modelling is a useful tool in order to delineate and to define the main features of every geothermal system and reservoir thus must be updating as well as new data is being available. The main components for the conceptual model must include at least: heat source location, up flow and out flow areas, flow patterns into the system, the cap rock and basement formation as well as the reservoir formation, thermal conditions of the reservoirs if it is being possible. To achieve this, good correlation is needed between the information available including geological, geophysics, chemistry and well data. In this paper, there are presented several conceptual models constructed during more than 20 years of commercial operation of the Berlin geothermal field, El Salvador. Some uncertainties are being observed in all models due to the nature of volcanic hydrothermal geothermal systems. Additional studies must be developed in the near future.

1. INTRODUCTION

Conceptual modelling is the task where all the information gathered around a whole field is putting together in one drawing, the model integrates all data gathered among geological setting, geochemical, geophysical techniques and well data all of them to delineate the geothermal system, assess the resource capacity, and understand the reservoir chemistry, temperature and hydrological structure. This conduct with a high level of confidence to exploratory drilling and field delineation thus to reduce cost and risk. The conceptual model must provide the update understanding of geothermal reservoirs and systems.

The conceptual model is important for geothermal development in every field, among other uses, the conceptual models is essential for well targeting, well completion design and resource assessment, if the conceptual model is quite refined the resource risk must be reduced.

In this paper are presented several conceptual models developed at the Berlin Geothermal field in El Salvador which has been constructed since beginning of the commercial exploitation. The models were improved as new data was available i.e. geophysical survey, geological data and well drilling. Spite several models, at the moment some uncertainties has been identified due mainly to dynamic condition of the reservoir and constraints of the studies involved and also due to nature of the geothermal resource involved.

The conceptual model must delineate at least the following issues:

a) The heat source where the main convective and conductive heat flow is coming to the geothermal systems and reservoir. Caldera structures, active faulting systems, liquid/gas/isotopes geo thermometer from fumaroles, mud pools or thermal springs, and finally formation temperature could help to determine the location of heat source.
b) Permeable and productive layer where the reservoir is located. The flow pattern must be defined through resistivity anomalies (conductive layer overlaying resistive layer) MT/DC resistivity surveys is the standard methodologies, if is available, the seismicity mapping (passive or active) could contribute, the down hole pressure and temperature profiles with iso-contour mapping is also important to delineate the reservoir. The geological setting of main fault is also considered invaluable for this issue.
c) Due to the hydrothermal reservoirs are frequently confined or quasi confined, the cap rock and basement layers could be established mainly in the reservoir area.
d) The up flow and the possible out flow of the systems are also important part of the conceptual model.

2. THE BERLIN GEOTHERMAL FIELD.

The Berlin geothermal field is located 110 km towards to the East part of El Salvador where the Tecapa volcanic complex is located. In year 2000 the energy regulator Superintendencia General de Energia y Telecomunicaciones (SIGET) awarded the concession contract to LaGeo which enabled it to utilize the geothermal resource to produce electricity. Figure 1 shows the regional location of the field, the concession covers 40 km^2 with surrounding towns of the Berlin at the south, Alegría to the east and Mercedes Umaña to the North

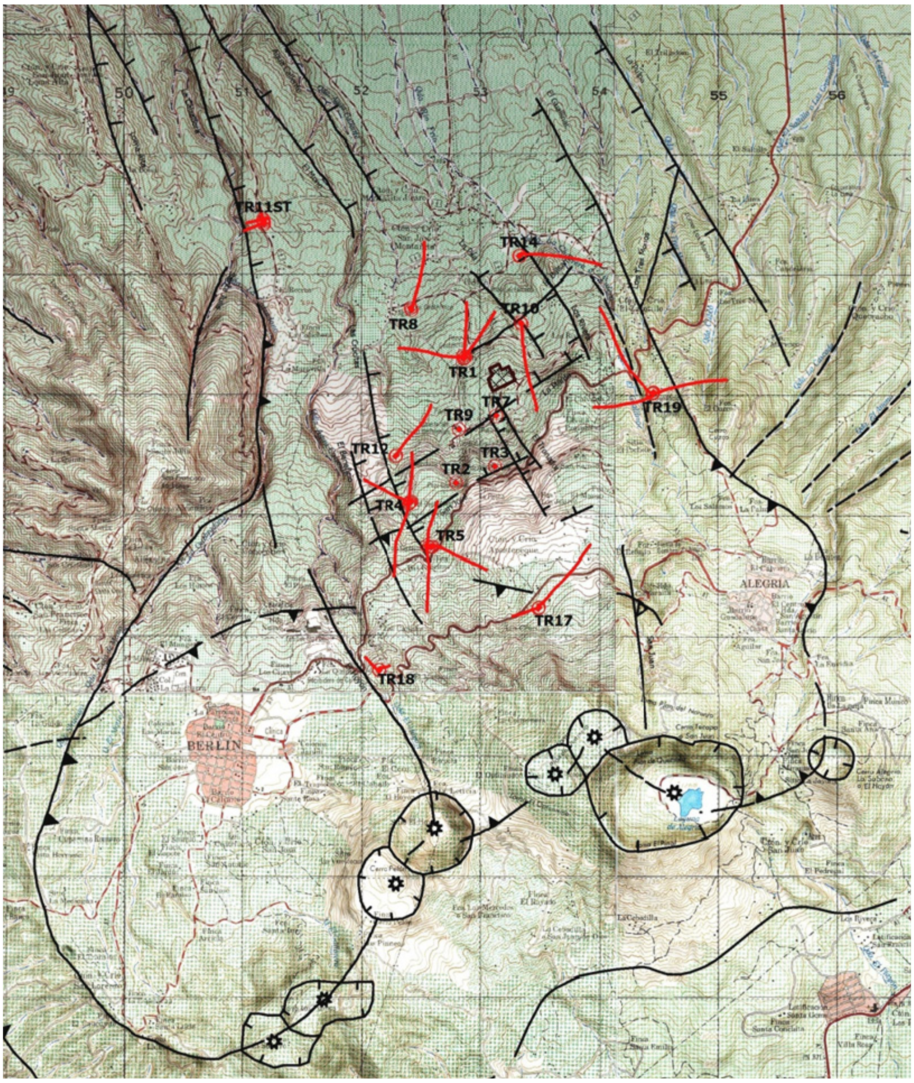

FIGURE 1: The location of the Berlin geothermal field

The field went to commercial operation (small scale) in 1992 with 2x5 MW back pressure units. Later on during 1999 went on line 2x28 MW condensing type units, during 2006 went on line 1x44 MW condensing type unit and finally in 2007 went on line the 9.2 MW binary bottoming unit to complete the 109.2 MW currently installed capacity. Figure 2 presents the well location into the field, the steam field is located to the southern part and the main injection area is located to the northern part of the steam field.

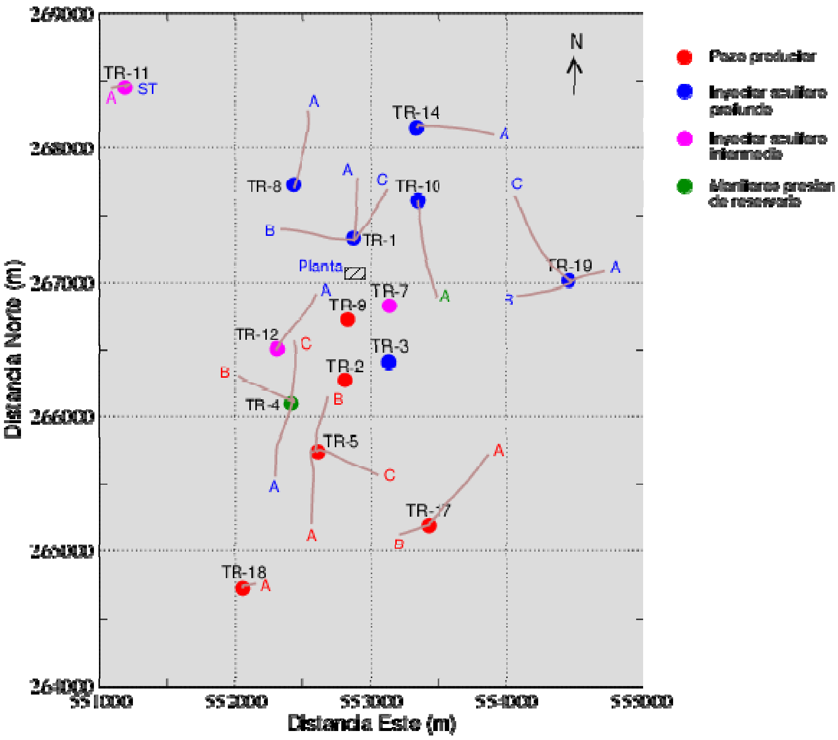

FIGURE 2: Wells location at the Berlin geothermal field

At present, 38 wells were drilling at the Berlin field, 14 of them are producers and 20 injectors (4 are abandoned). The total mass extracted which ranges 870 kg/s, the steam delivered to the power plant is approximately 220 kg/s and the injected brine is 650 kg/s which is partially injected using high pressure pumping system located al TR-1 site. The Figure 3 presents the production history of the field since year 2000 when the concession was granted the field and it is possible to observe when unit 3 went on line in late 2006.

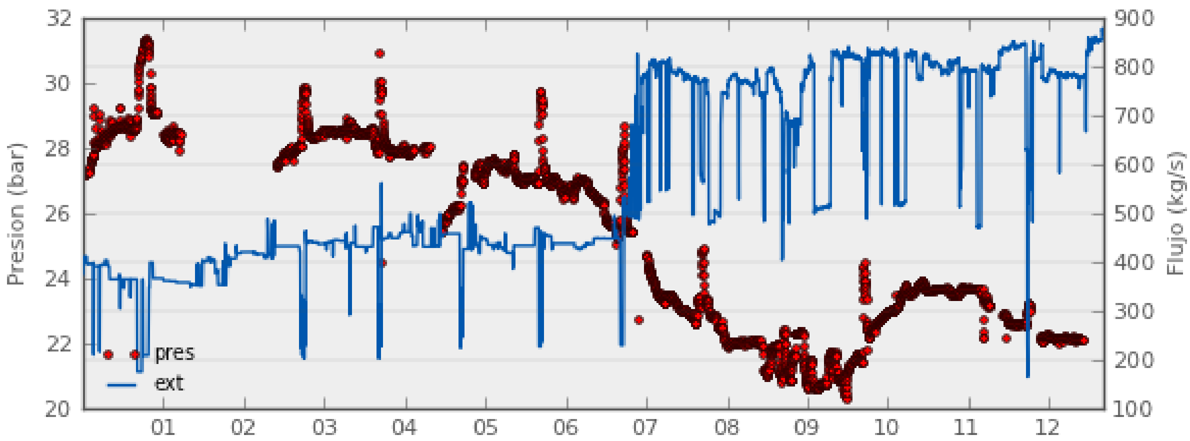

FIGURE 3: Production history of the Berlin field

2. CONCEPTUAL MODELS OF THE BERLIN FIELD

2.1 1996 conceptual model

This conceptual was developed in the early stage of the development in order to assess the feasibility for large scale exploitation. This model was constructed in 1996, and is show in the Figure 4. The results of the model delineate the following:

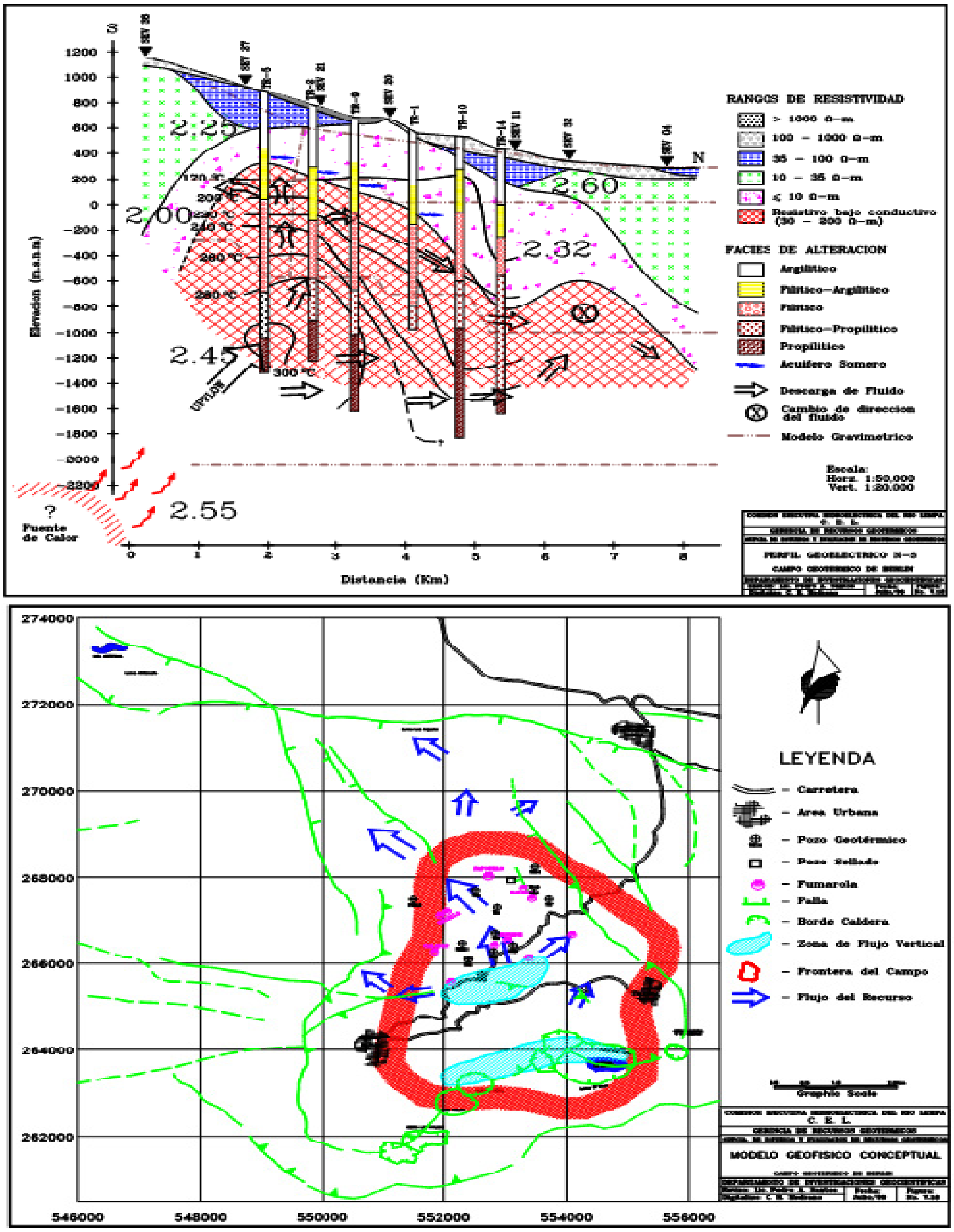

FIGURE 4: 1996 conceptual model for the Berlin field (CEL, 1996)

a) The up flow zone is located close to the production well pads TR4´s andTR-5´s which could be associated with the presence of a resistivity core and a positive gravity anomaly. A second up flow area was also proposed along the volcanic axis.

b) There are evidences of two thermal aquifers: an inter-mediate sea level with temperature around 150-200 °C which was identified by vertical electrical soundings and well drilling data, and the reservoir aquifer with temperature ranges 290-300 °C which is located below and separate for a cap rock.

c) The flow path is from the South to the North-West following the graven trend.

d) The reservoir is perhaps related to 30 Ω-m contours which are considered as deep resistive.

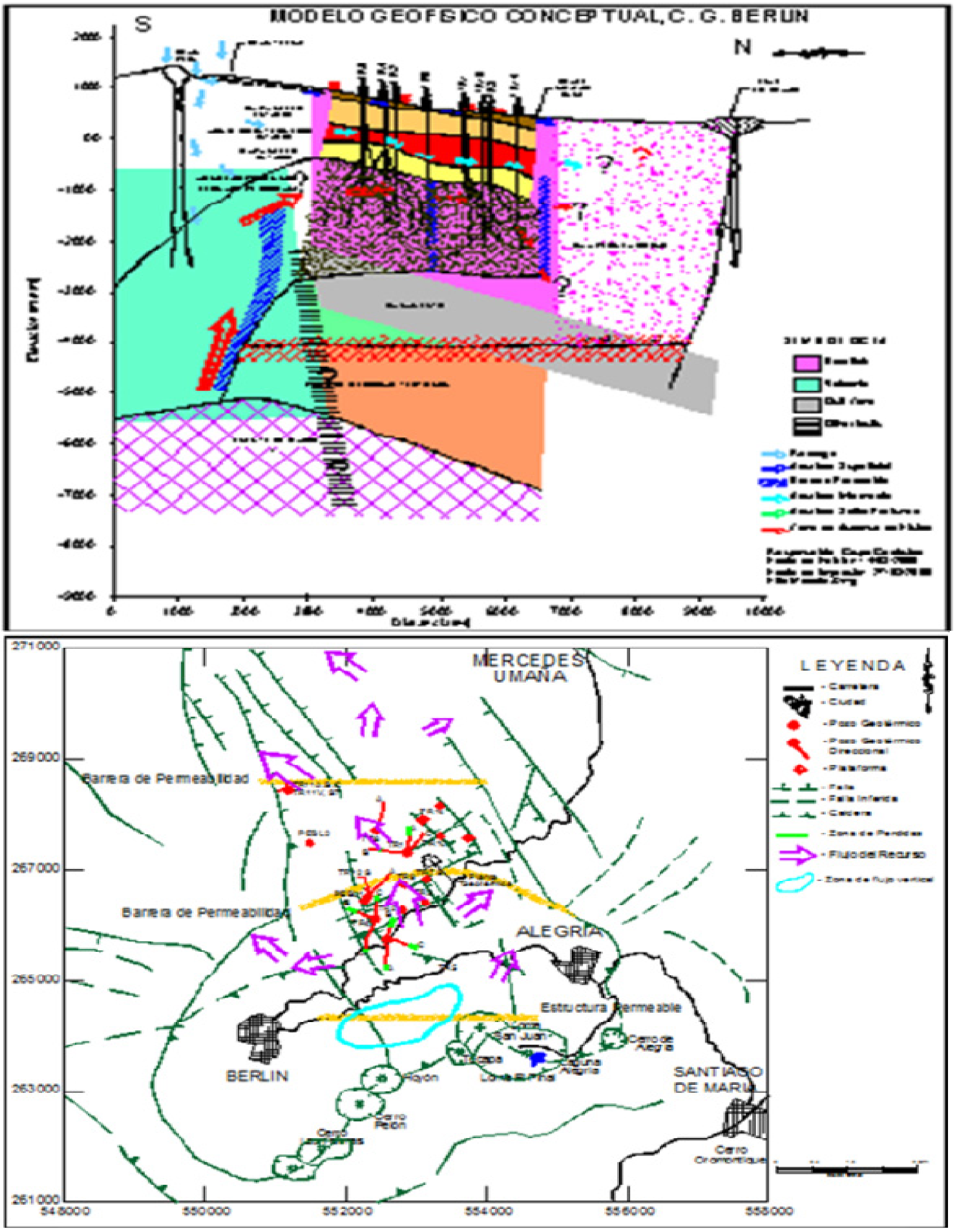

FIGURE 5: Year 2000 conceptual model for the Berlin field (GESAL, 2000a; 2000b)

2.2 Year 2000 conceptual model

In order to update the conceptual mode, new data was gathered during drilling of new wells, MT surveys were carried out by GENZL and 4 years passive seismicity monitoring, prior to starting the large scale exploitation. This model is presented in the Figure 5. Besides the main aspects detailed in previous model, some new additional results were observed:

a) At least three permeability barriers were under consideration and proposed in this new model.

b) The up flow is being associated along the volcanic axis which is supported by passive seismicity.

c) The almost 30-40 °C cooling down between the wells TR-1 and TR-9 was correlated with the Northern edge of the Berlin caldera which was the results of gravity surveys which represents perhaps the permeability limit between producer and injection wells.

Figure 6, on the other hand, shows the model proposed by GENZL (2000).

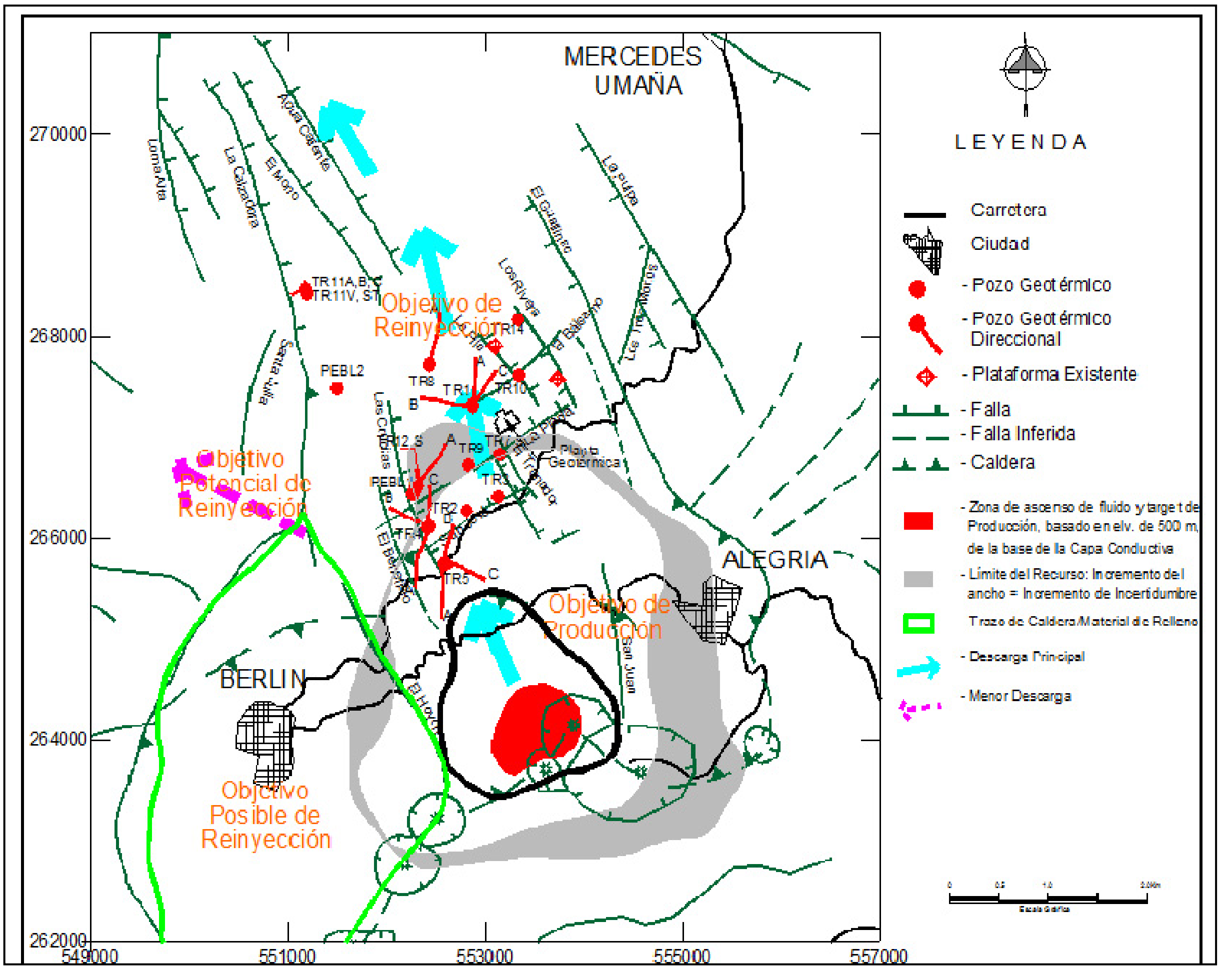

FIGURE 6: The Berlin conceptual model proposed by GENZL (2000)

2.3 2003 conceptual model

To assist in carrying out the feasibility study for Unit 4 an updated conceptual model was delivered in 2003, this model is shows in the Figure 7, besides previous results the new data indicate the follow:

a) The producer reservoir is characterized by the presence of a resistive deep with resistivity above 40 ohm-m in correspondence with the occurrence of prophylitic facie, whose formation temperature is in the range of 240-300°C.

b) A possible extension of the reservoir was suggested to the southeast of the production area.

c) A new conductive body was observed (DVC) which is related to western edge of the reservoir.

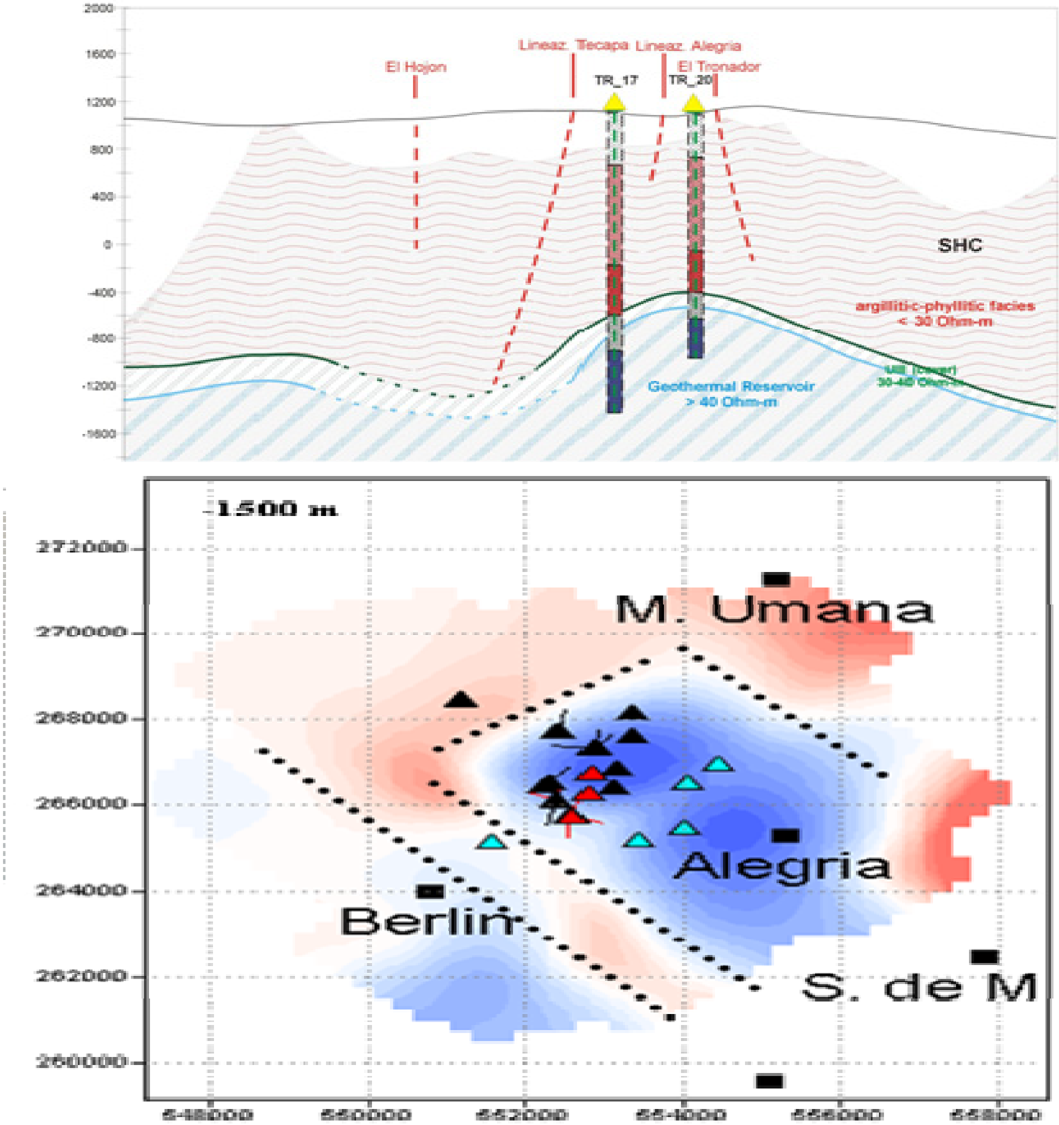

FIGURE 7: 2003 conceptual model of the Berlin field (LaGeo, 2008)

2.4 2008-2012 conceptual model

Several updated conceptual models have been developed by LaGeo, not shown in this paper. The following can be mentioned here:

a) Updated model with MT and CSAMT data in 2001 (West JEC, 2001).

b) Updated model with MT and TDEM surveys and 3D modelling, in 2005.

c) Finally, updated models from 2008-2012 which are the ones currently used. Figure 8 shows this model (LaGeo, 2008).

Despite the large quantity of available data there are still some features of the reservoir, which have not been defined or delineated, which must be evaluated in the future. The main ones are the following:

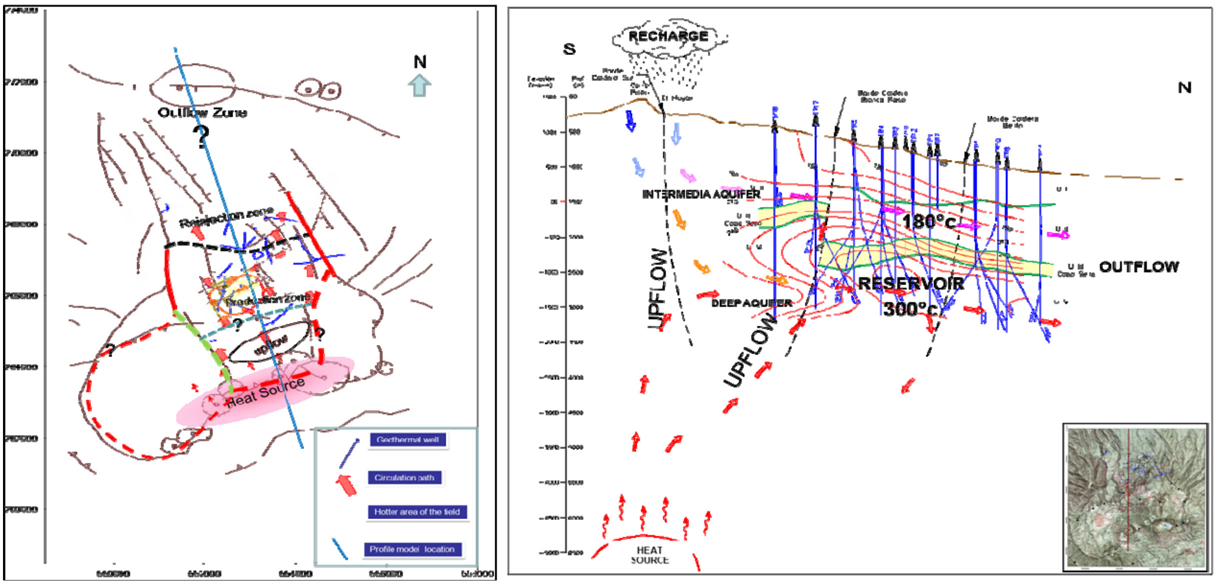

FIGURE 8: The 2008-2012 conceptual model of the Berlin field (LaGeo, 2008)

a) There are permeable connections between both aquifers observed in well TR-18

a) The temperature decline in the southern part wells is due to some out flow condition or perhaps down flow in the systems in that area.

b) The permeability difference between TR-9 and TR-1 is correlated to the caldera border or due to unknown condition.

c) It could be possible to intersect a 300°C reservoir in the southwest part of the actual bore field or possibly connect to the current aquifers being observed in other wells.

d) Where is the out flow of the systems? Is it correlated with some of the hot springs located to the North or are there other unknown flow paths which were not indicated in the surveys that have been undertaken.

3. CONCLUSIONS

1) The conceptual modelling is still an important tool to achieve a good understanding of the geothermal system on where the energy resource is located. The model is useful to delineate the reservoir and its conditions which is an important input for well targeting and resource assessment.

2) The conceptual model must include at least geological setting, geophysical data, chemistry of the fluids and well data. With this information the model must define heat source location, flow path into the reservoir and system, especially, the up flow and out flow, cap rock and basement, aquifers in the systems, thermal condition, etc.

3) Despite the number conceptual models having been developed and the large data available gathered during 20 years of commercial exploitation a completely "well known" systems is perhaps not a correct expression due to large uncertainties found in nature, especially associated with volcanic anisotropic systems.

4) A reliable conceptual model can be constructed with available data but must be updated when new additional data is becomes available.

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